$B \to h^+h^-$ at CDF

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for the CDF collaboration

Wine&Cheese seminar
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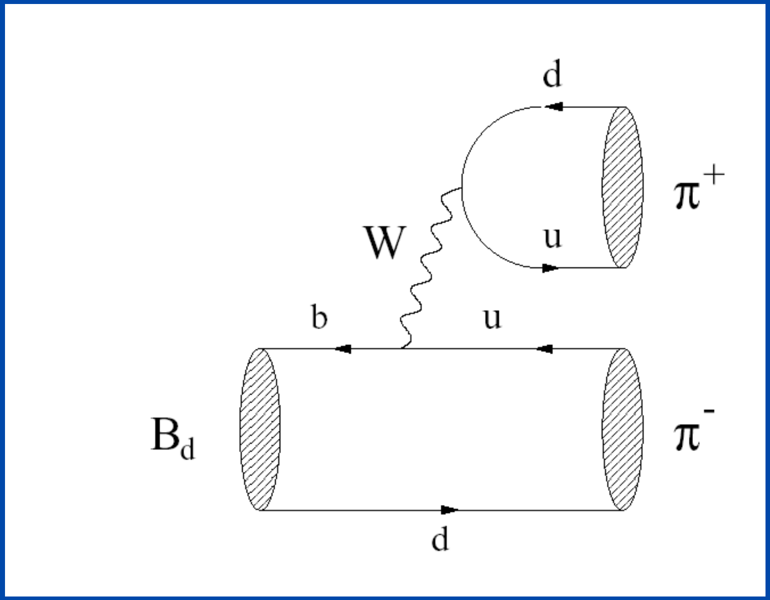
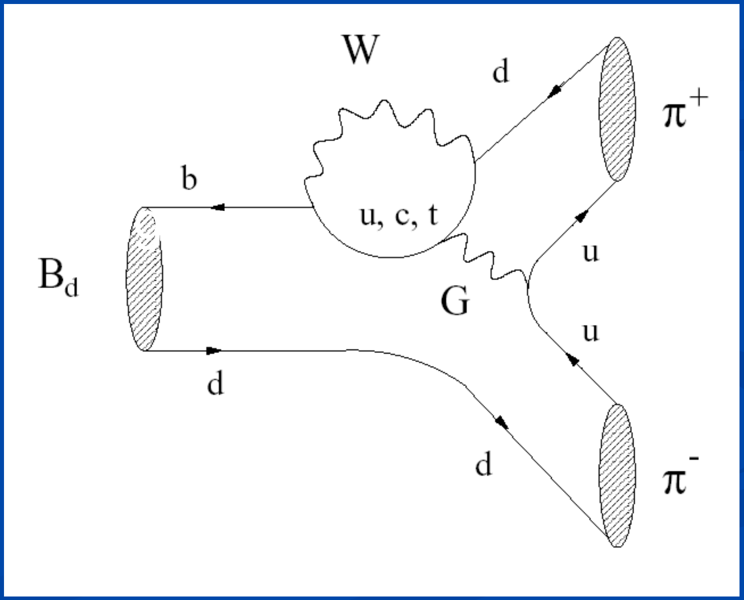
Outline

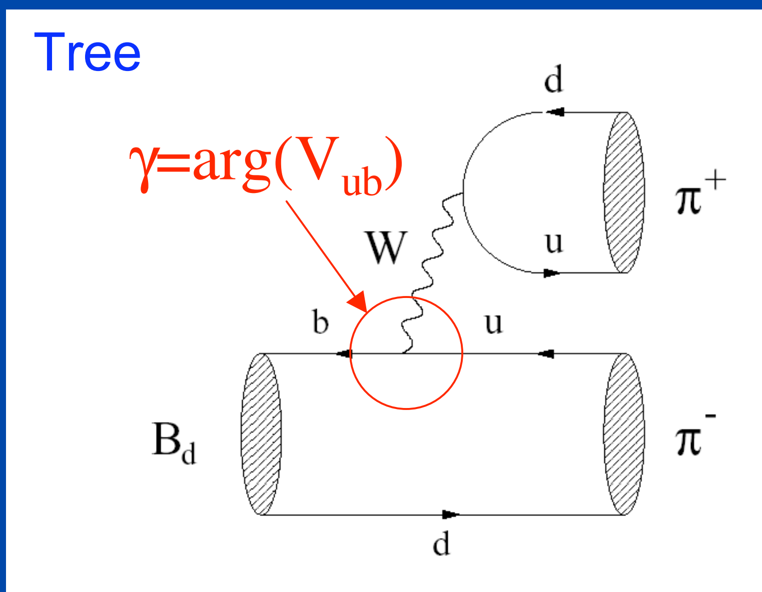
- Why $B \rightarrow h^+h'^-$ decays are interesting
- How we reconstruct them at CDF
- CDF results with a ~1 fb^{-1} sample.
  (Previous results used 180pb-1 or 360pb-1)

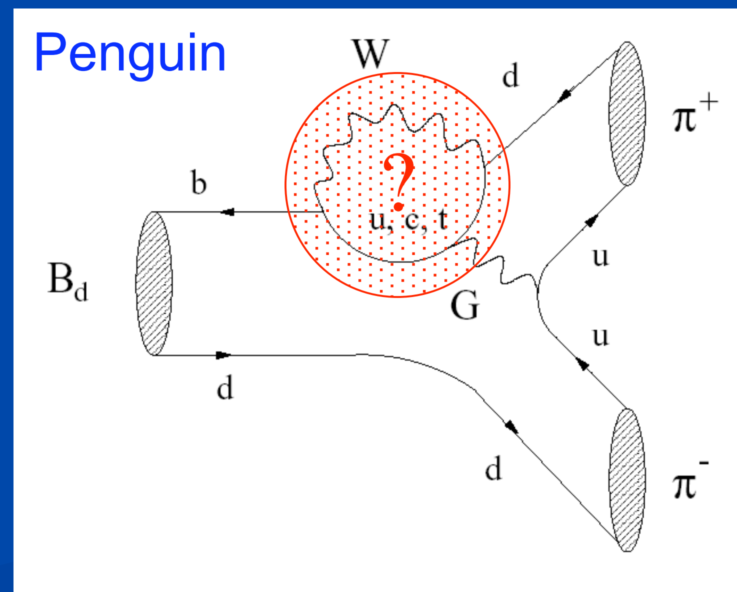




Charmless decays B→(ππ/Kπ/KK)

- The charmless decay modes of B hadrons are a great tool for probing the quark mixing matrix.
- The b→u transition makes them sensitive to angle γ (phase of Vub), and to possible New Physics effects in Penguin diagrams.





Charmless decays $B \to (\pi\pi/K\pi/KK)$

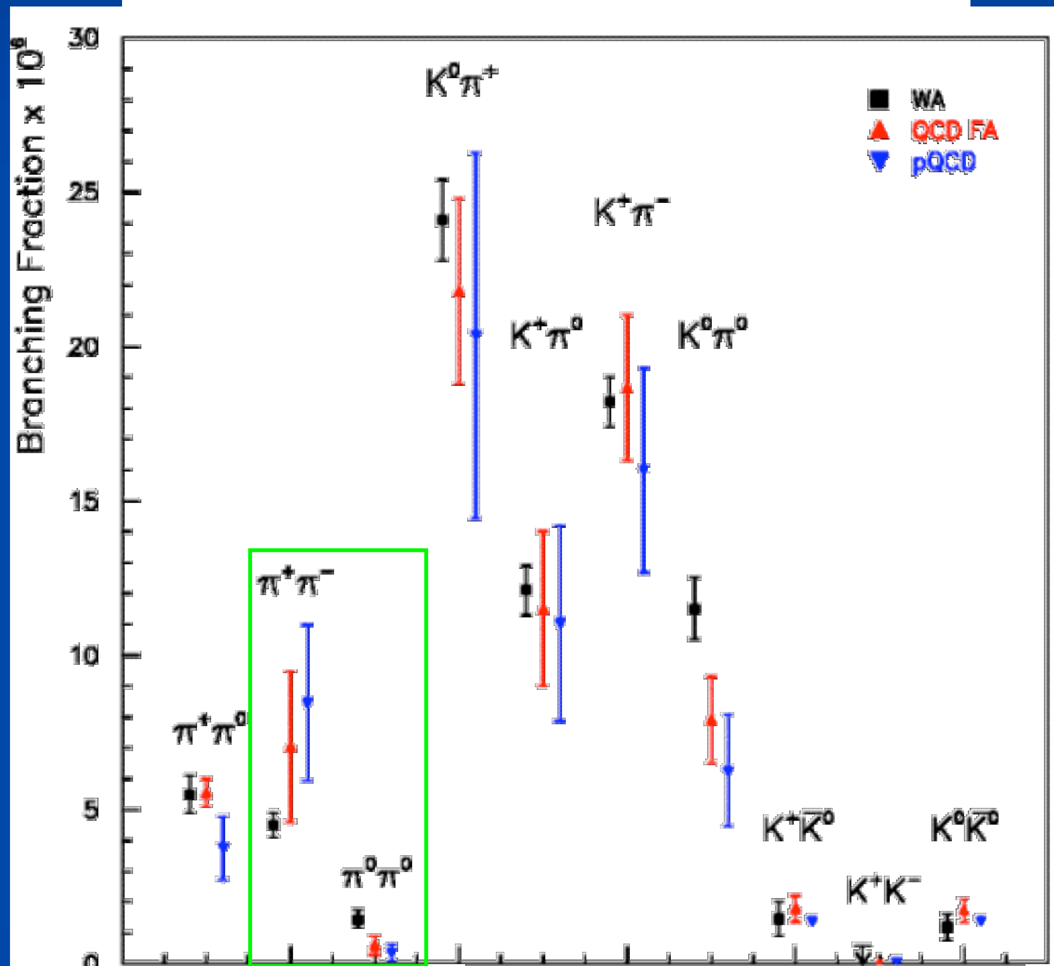
- The original CLEO finding of $BR(B^0 \to K^+\pi^-) \gg BR(B^0 \to \pi^+\pi^-)$ revealed the importance of contributions beyond the tree level.
- Interplay of multiple amplitudes makes them rich, but complex (Tree, Penguins, Annihilation…)
- Measurements on B^0 and B^+ in recent years have provided a wealth of useful information, and theoretical work has flourished to interpret them:
  - QCD Factorization (QCDF): Beneke, Buchalla, Neubert & Sachrajda (1999–2001); ...
  - Perturbative Hard-Scattering (PQCD) Approach: Li & Yu ('95); Cheng, Li & Yang ('99); Keum, Li & Sanda ('00); ...
  - Soft Collinear Effective Theory (SCET): Bauer, Pirjol & Stewart (2001); Bauer, Grinstein, Pirjol & Stewart (2003); ...
  - QCD light-cone sum-rule methods: Khodjamirian (2001); Khodjamirian, Mannel & Melic (2003);
  - Simmetries: SU(3), isospin: Fleischer, Gronau….
- The presence of hadronic parameters calls for collecting a diverse sample of data, to allow canceling out hadronic parameters by taking ratios and performing global fits

Example: BR($B^0 \to hh$)

Most results well described, but not all.

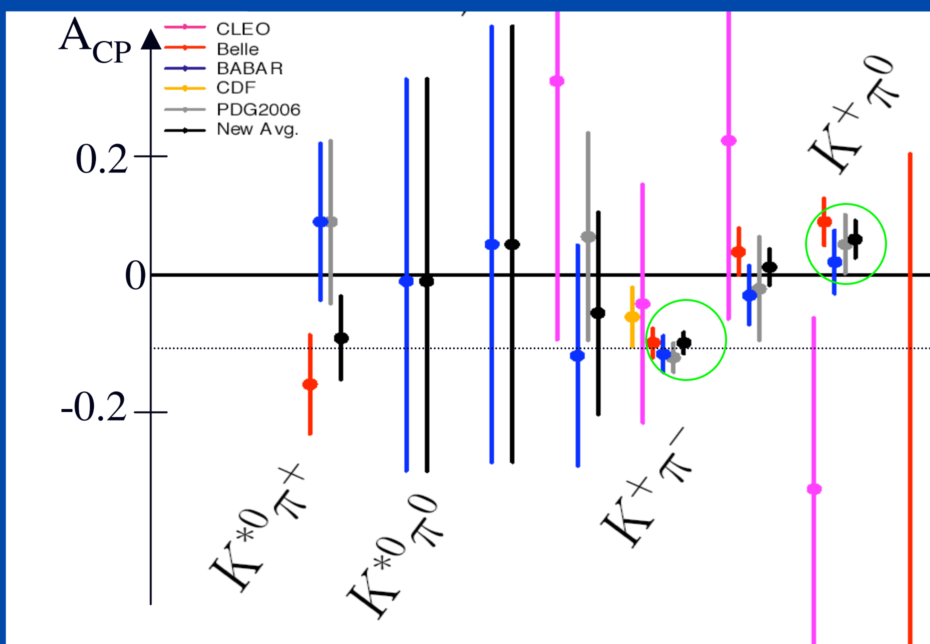
The growth of data and improvement of predictions leads to the ability to detect discrepancies and reveal New Physics.

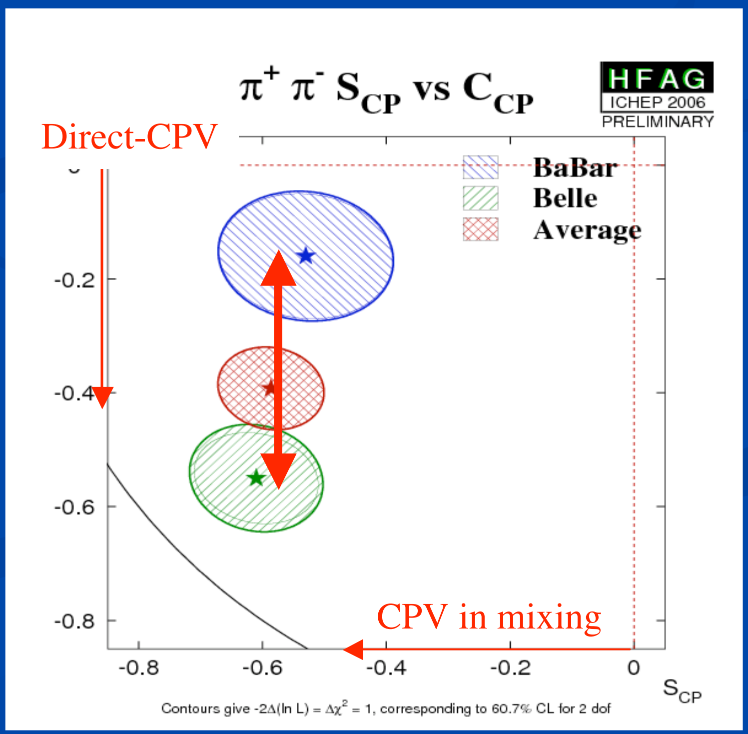
WA World average [EPS 2005]
QCD FA Beneke and Neubert (hep-ph/0308039)
pQCD Keum (hep-ph/0410337)



CP violation

- CP violation is special interest: understand CKM + detect NP via anomalies
- Mixing-induced CP violation provides information on CKM angle α.
- Direct CP violation a probe into new effects. Unfortunately not easy to predict.
  - Requires interference of two amplitudes with different weak and strong phases.
- Direct CP Violation in $B \to \pi\pi$ in *disagreement* in the two e+e- B-factories.
- DCPV easier to measure in self-tagging modes. Only seen in $B^0 \to K^+\pi^-$, but the expected similar effect in B+ is not there: *New Physics ?* More data can help, in particular from Bs modes, not yet explored by Babar and Belle

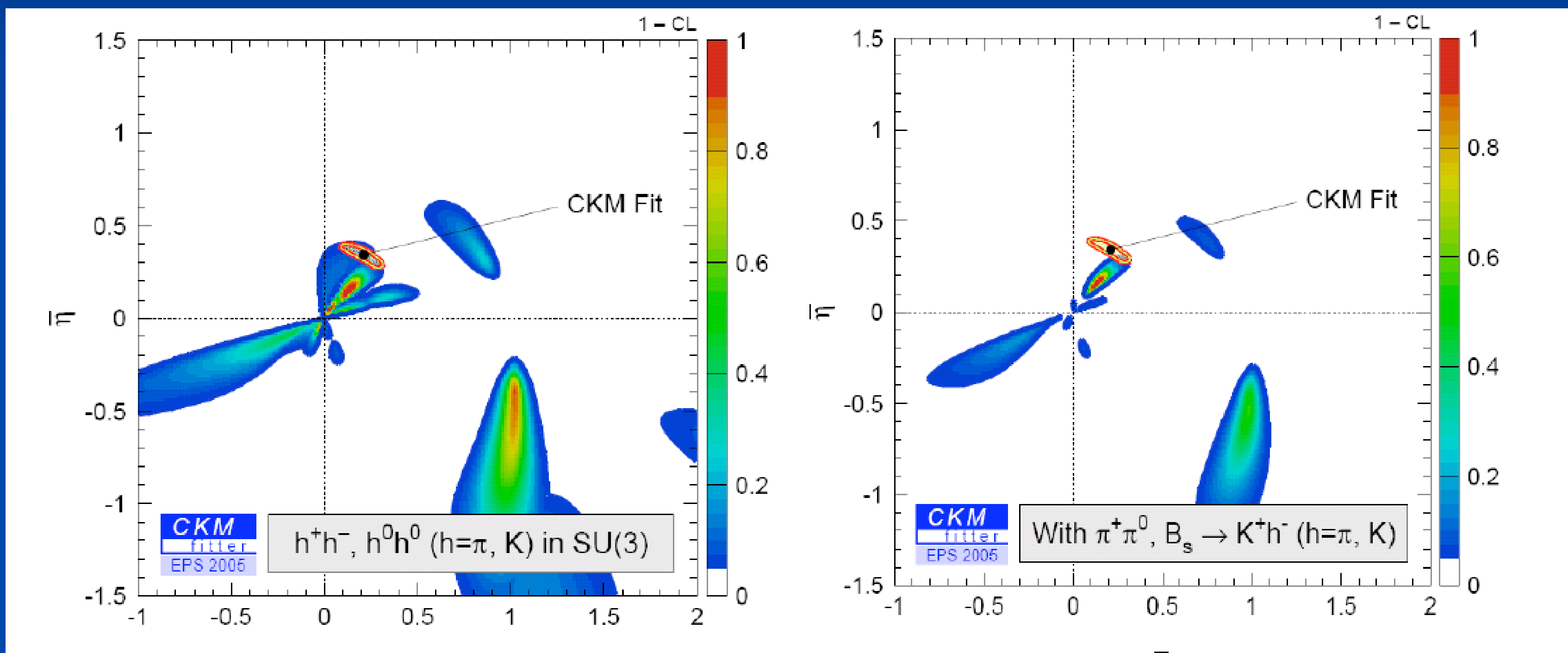




The impact of Bs

Measurement on other B hadrons extends our understanding

Example of the effect of adding Bs information to a global BR fit:



The right plot is obtained using CDF data from 180pb-1 [hep-ex/0607021, PRL in press]

This particular example uses the approach of parameterizing SU(3) breaking and fitting the relevant parameters from data [Malcles, hep-ph/0606083].

Many other methods are possible.

Impact of the $B_s \rightarrow KK$ mode

Time-dependent CP asymmetries

$$A_{cp}(t) = A_{cp}^{dir} \times \cos\Delta m t + A_{cp}^{mix} \times \sin\Delta m t$$

$$A_{cp}^{dir}(\pi^+\pi^-) = -\frac{2d\sin\theta\sin\gamma}{1-2d\cos\theta\cos\gamma+d^2}$$

$$A_{cp}^{dir}(K^+K^-) = \frac{2d\frac{1-\lambda^2}{\lambda^2}\sin\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+(\frac{1-\lambda^2}{\lambda^2})^2 d^2}$$

$$A_{cp}^{mix}(K^+K^-) = \frac{\sin 2\gamma+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+d^2(\frac{1-\lambda^2}{\lambda^2})^2}$$

$$A_{cp}^{mix}(\pi^+\pi^-) = \frac{\sin 2(\beta+\gamma)-2d\cos\theta\sin(2\beta+\gamma)+d^2\sin 2\beta}{1-2d\cos\theta\cos\gamma+d^2}$$

$$A_{cp}^{mix}(J/\psi K_s) = \sin 2\beta$$

[R. Fleischer, Phys. Lett. B 459, 306]

CP asymmetries related to $B^0 \rightarrow \pi\pi$ by U-spin relationship: determine angle γ and provide tests for New Physics.

BR is an interesting issue: several contrasting predictions exist, testing them will improve understanding of the models and can also reveal New Physics

In addition, allows measuring $\Delta\Gamma$s.
CDF has already performed a measurement on 360pb-1.

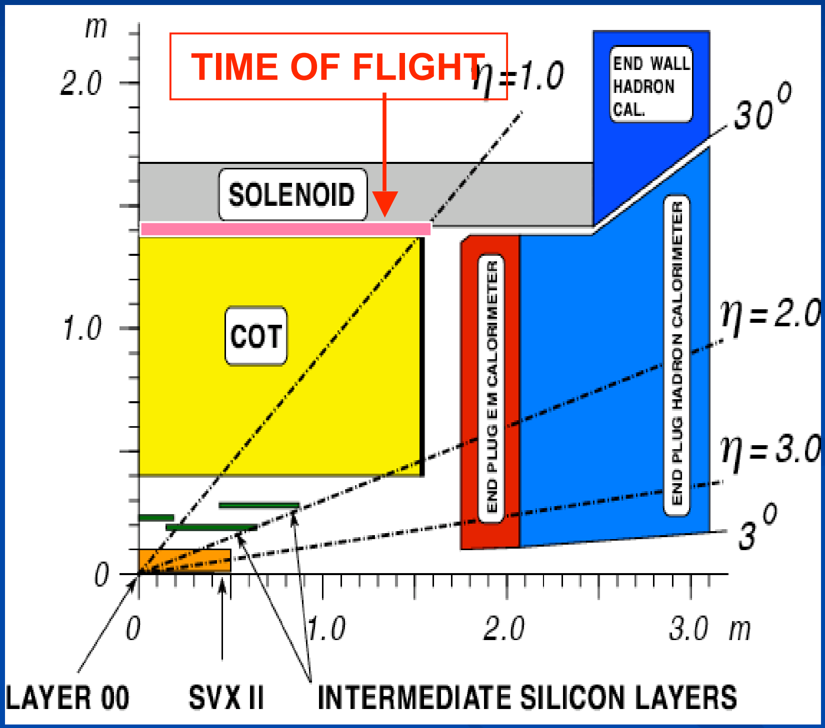
$B^0 \to hh$ at CDF

- The Tevatron has a lot to offer to this field:
  - Large B production and large Luminosity mean big samples
  - Access to all b-hadrons allows wide range of measurements
- We can look for all combinations of $\pi^\pm$,$K^\pm$ from Bs, Bd, Λ_b :
  - Known modes (larger BR):
    - $B^0 \to K^+\pi^-$
    - $B^0 \to \pi^+\pi^-$
    - $B^0_s \to K^+K^-$
  - Yet unobserved modes:
    - $B^0_s \to K^-\pi^+$
    - $B^0 \to K^+K^-$
    - $B^0_s \to \pi^+\pi^-$
    - $\Lambda_b \to pK$
    - $\Lambda_b \to p\pi$

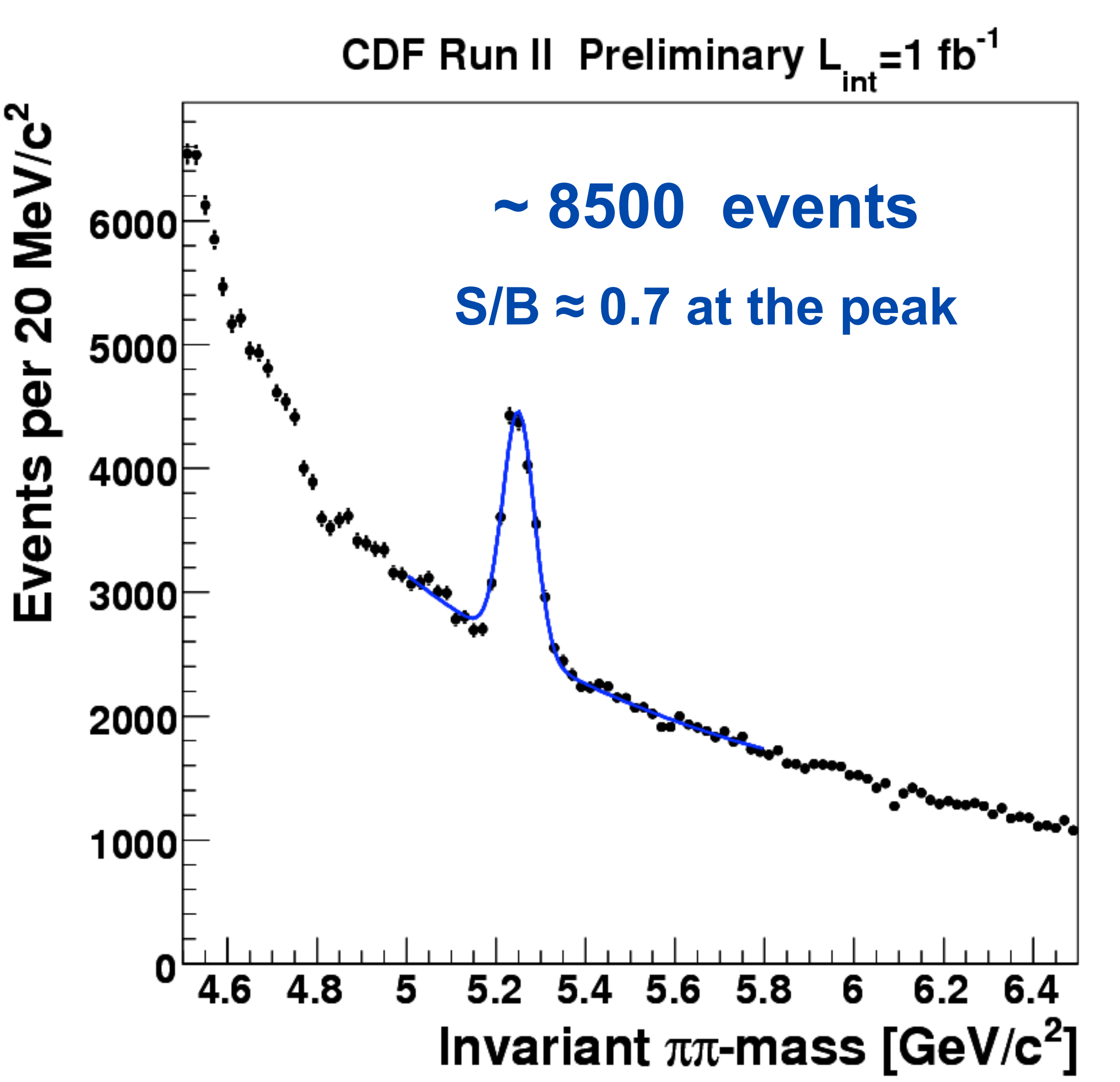
We just need to reconstruct them…

Important CDF features

- Central Drift chamber
  - $\sigma(p_T)/p_T^{\,2} \sim 0.15\%\ \mathrm{GeV}^{-1}$
  - dE/dx measurement, encoded in hit width
- Silicon Vertex detector
  I.P. resolution 35μm@2GeV
- Time of Flight
  - Used to measure the asymmetry of the proton background, to reduce systematics
- Tracking trigger:
  - XFT at L1, 2D tracks in COT, p_T >1.5 GeV
  - SVT at L2, 2D tracks p_T>2 GeV, Impact parameter measurement



Signal with initial cuts



Signal (BR ~ 10^{-5}) clearly visible with just trigger cuts confirmation

Variables used for further analysis:

- 3D Vertex chi-square
- Isolation: rejects light quark background (analog of event shape for e+e-)

$$I(B) = \frac{Pt(B)}{Pt(B) + \Sigma_{cone} Pt_i}$$

Choice of cuts

Cuts individually optimized by minimizing the expected statistical uncertainty on the quantity of interest. Its expression $\sigma(S,B)$ is determined from actual uncertainties observed in analysis of MC samples, and parameterized by an analitically-inspired model.

Signal yield S is derived from MC simulation while the background B is estimated from mass sidebands on data.

In practice, only 2 sets of cuts were needed:

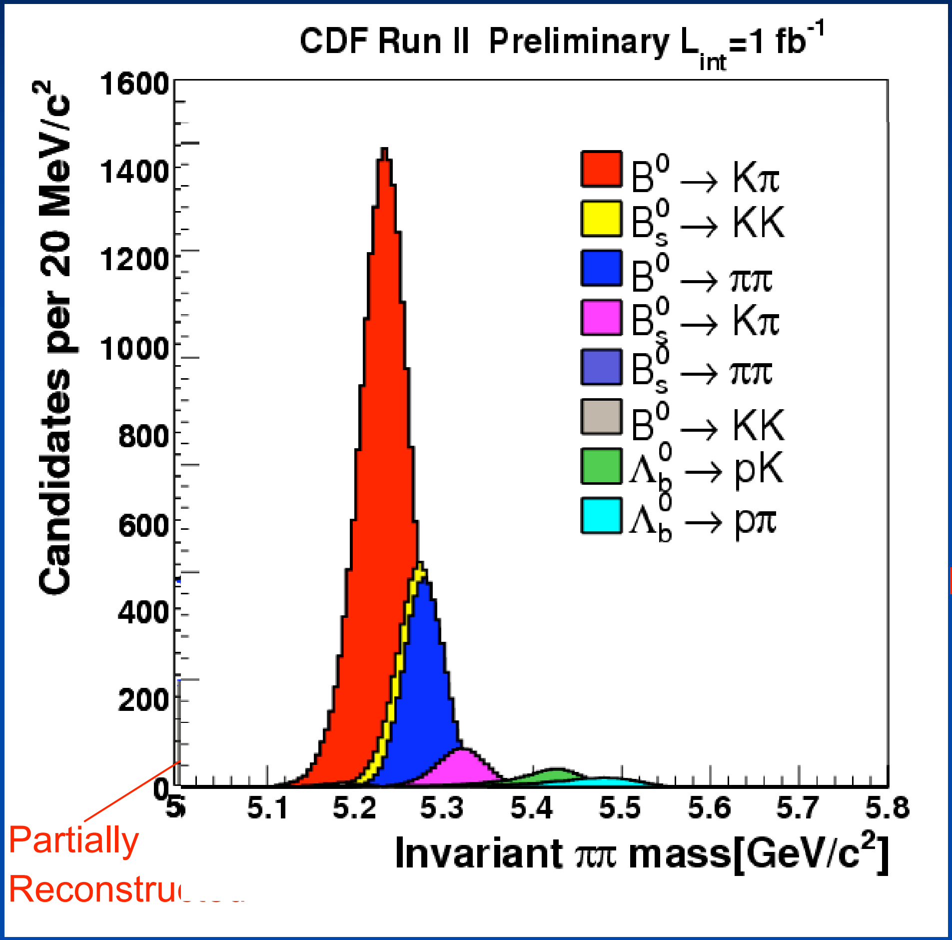
- (1) optimize on $A_{CP}(B^0 \to K^+\pi^-)$ => Loose cuts
    - good for all three "large modes" ($B^0 \to K^+\pi^-$, $B^0 \to \pi^+\pi^-$, $B^0_s \to K^+K^-$)
- (2) optimize on $B^0_s \to K^-\pi^+$ ***discovery*** [physics/0308063] $\Rightarrow$ tight cuts
    - good for all "rare modes"

When compared with $S/\sqrt{(S+B)}$:

~10% better on $A_{CP}(B^0 \to K^+\pi^-)$

~27% better on $BR(B^0_s \to K^-\pi^+)$

Loose cuts



Despite good mass resolution (≅22 MeV/c²), individual modes overlap in a single peak (width ~35 MeV/c²)

Note that the use of a single mass assignment ($\pi\pi$) causes overlap even with perfect resolution

Blinded region of unobserved modes: $B^0_s \rightarrow K\pi$, $B^0_s \rightarrow \pi\pi$, $\Lambda^0_b \rightarrow p\pi/pK$.

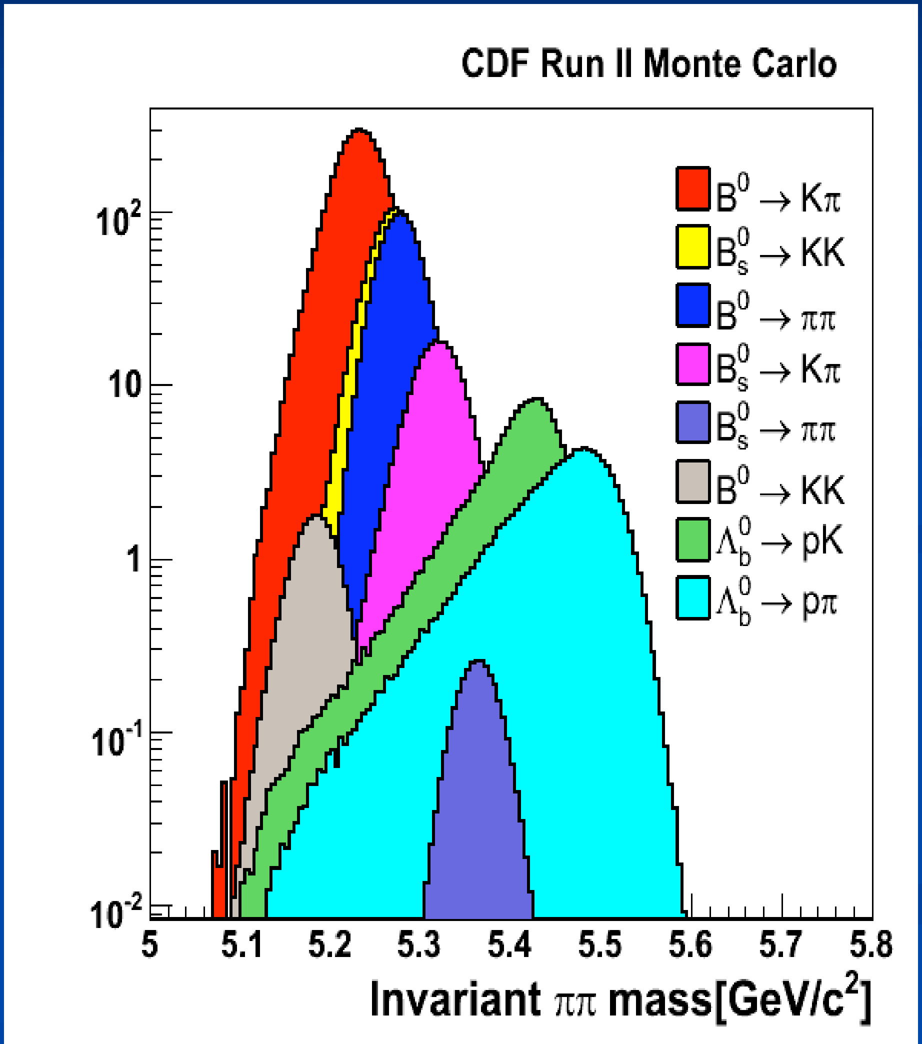
Need to determine signal composition with a Likelihood fit, combining information from kinematics (mass and momenta) and particle ID (dE/dx).

Handle 1:invariant mass

Different modes are somewhat separated in mass (~50 Mev between Bd->Kpi and Bs->KK)

However, results depend on assumed Mass resolution and details of the lineshape (rare modes confuse with the tails of larger modes)

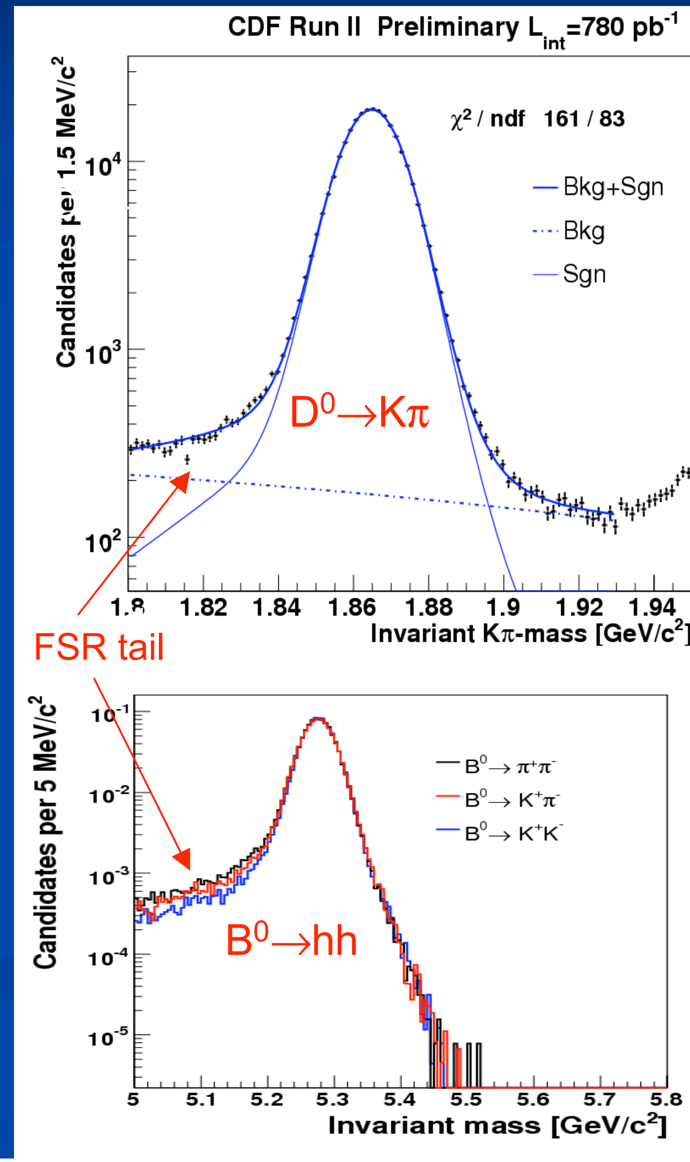
Need good control of non–gaussian resolution tails and radiative effects



Calibrating Mass resolution and tails from the $D^0 \rightarrow$Kpi peak

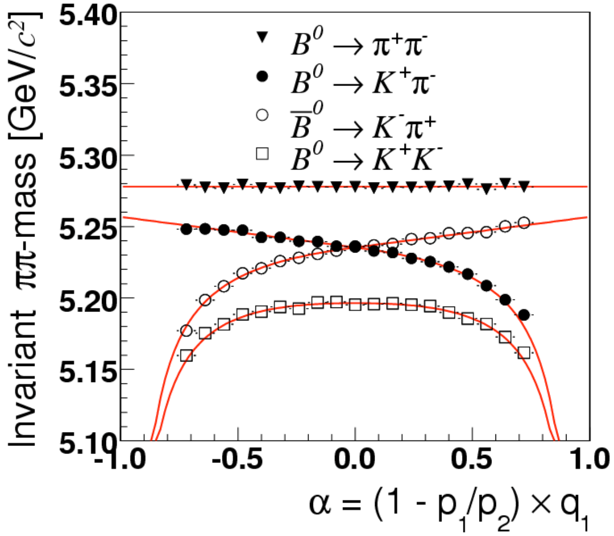
Method:

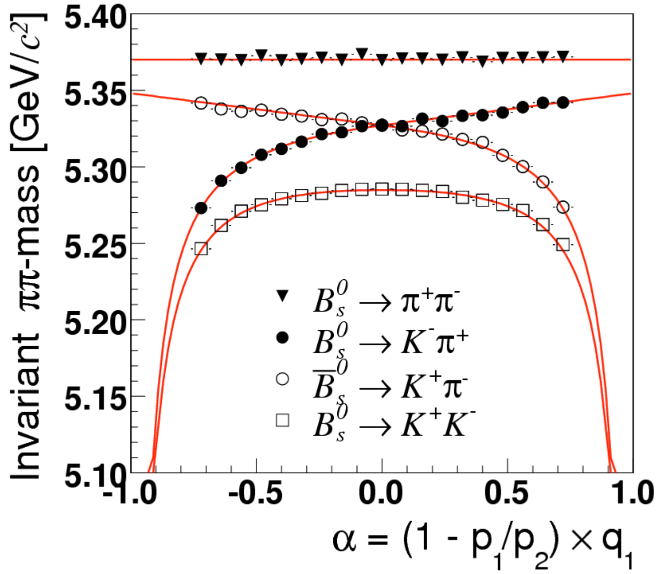
1. Accurate parameterization of *individual track parameters* resolution functions from full MC (including non-gaussian tails)
2. Add calculated QED radiation [Baracchini,Isidori Phys.Lett B633:309-313,2006]
3. Generate mass lineshapes with a simple kinematical MC
4. Compare results with a huge sample of $D^0 \rightarrow K\pi$
   $\Rightarrow$ perfect match, no tuning necessary $\Rightarrow$ small systematics
5. Generate $B \rightarrow hh$ templates and use them in the Likelihood fit.

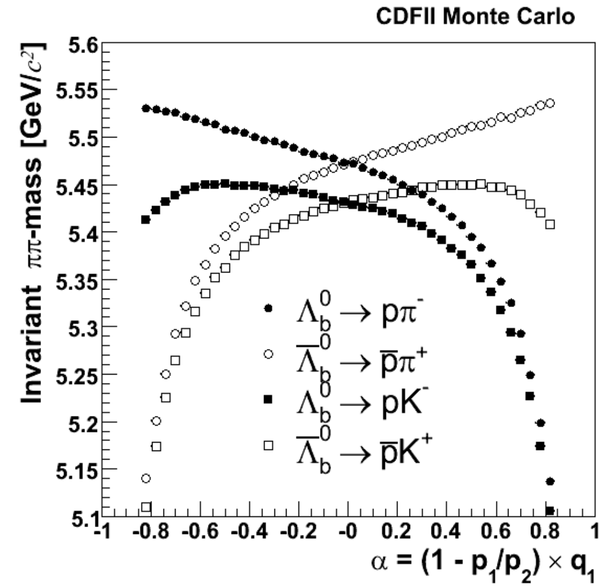


handle 2: track momenta

CDF MC







Kinematic variables:

p_{min} (p_{max}) is the 3D track momentum with $p_{min} < p_{max}$

1) $M_{\pi\pi}$ invariant $\pi\pi$-mass

2) $\alpha = (1-p_{min}/p_{max})q_{min}$ signed p-imbalance

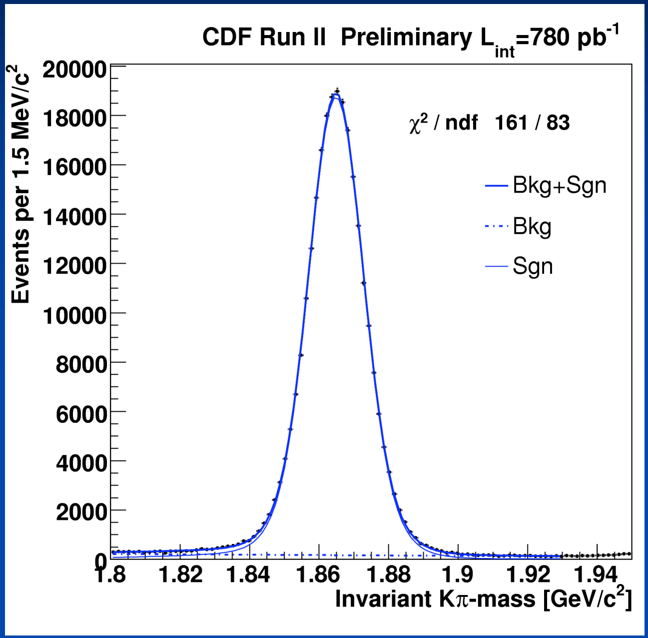
3) $p_{tot} = p_{min}+p_{max}$ scalar sum of 3-momenta

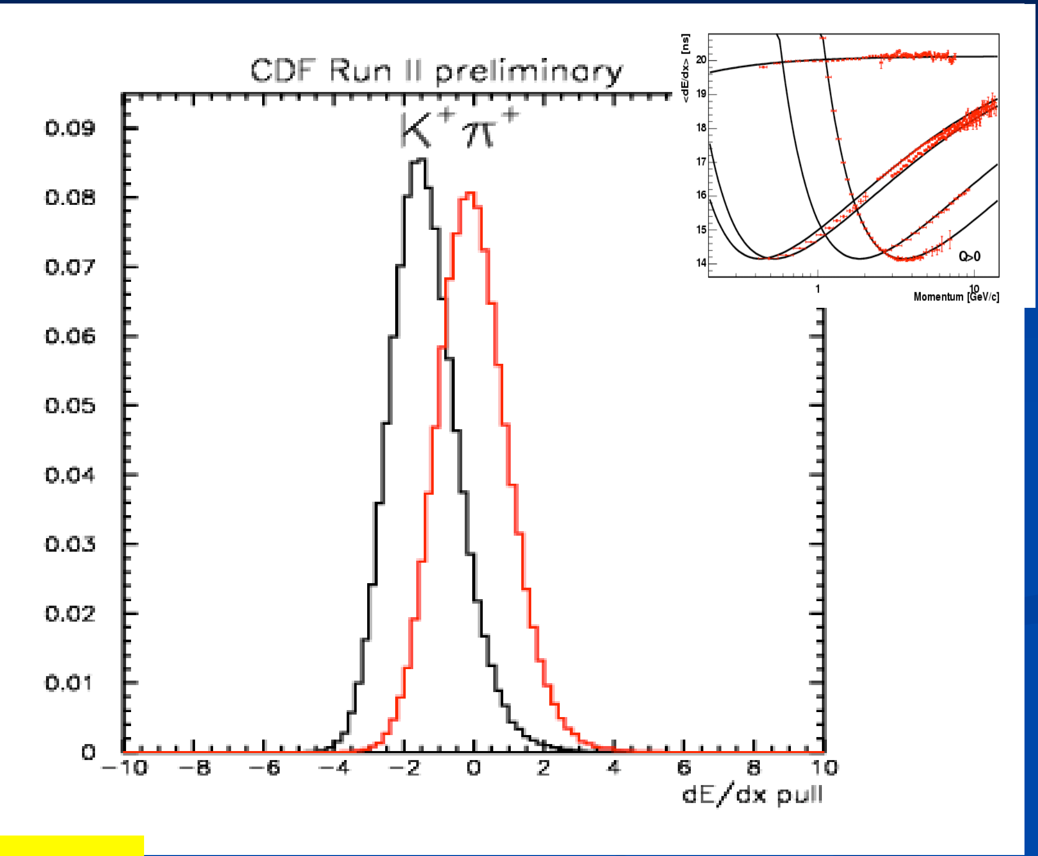
Each mode has an individual mass distribution $p(M_{\pi\pi}) = G(M_{\pi\pi} - F(\alpha , p_{tot}))$

This offers good discrimination amongst modes and between $K^+\pi^-$ / $K^-\pi^+$.

handle 3: dE/dx

$D^{*+} \to D^0\pi^+ \to [K^-\pi^+]\ \pi^+$





~95% pure K and π samples from decays: $D^{*+} \to D^0\pi^+ \to [K^-\pi^+]\ \pi^+$

Strong D^{*+} decay tags the D^0 flavor.
dE/dx accurately calibrated over tracking volume and time.
Detailed model includes tails, momentum dependence, two-track correlations

(**1.4σ K/π** separation at p>2GeV) achieve a statistical uncertainty on separating classes of particles which is only 60% worse than perfect PID

Putting it all together

Unbinned ML fit using 5 observables

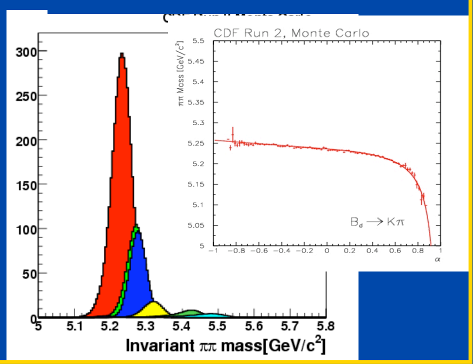
$$\mathcal{L}(\vec{\theta}) = \prod_{i=1}^{N} \mathcal{L}_i(\vec{\theta})$$

fraction of jth mode, to be determined by the fit

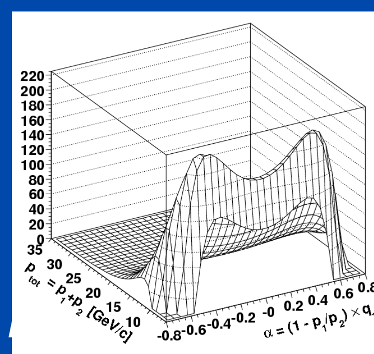
$$\mathcal{L}_i(\vec{\theta}) = (1-b)\sum f_j \mathcal{L}_j^{\text{sign}} + b\mathcal{L}^{\text{bckg}}$$

$$pdf_j^{\text{m}}(m_{\pi\pi}|\alpha, p_{tot}; \vec{\theta}) \cdot pdf_j^{\text{p}}(\alpha, p_{tot}; \vec{\theta}) \cdot pdf_j^{\text{PID}}(\text{ID}_1, \text{ID}_2|p_{tot}, \alpha; \vec{\theta})$$

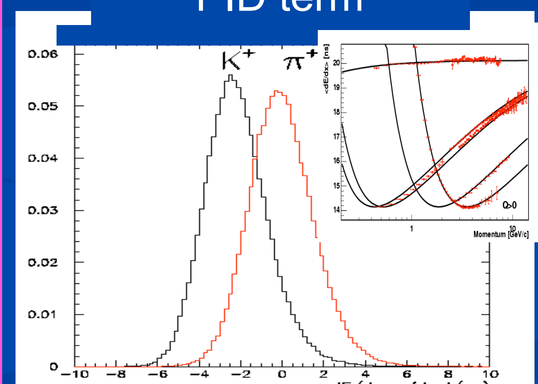
mass term



momentum term



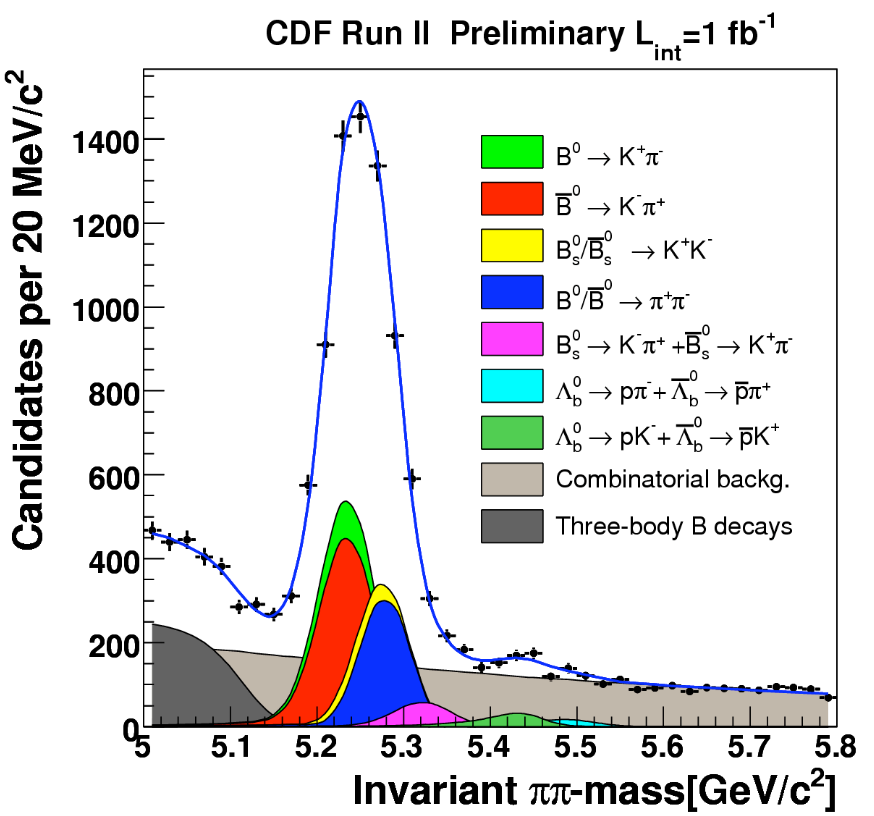
PID term

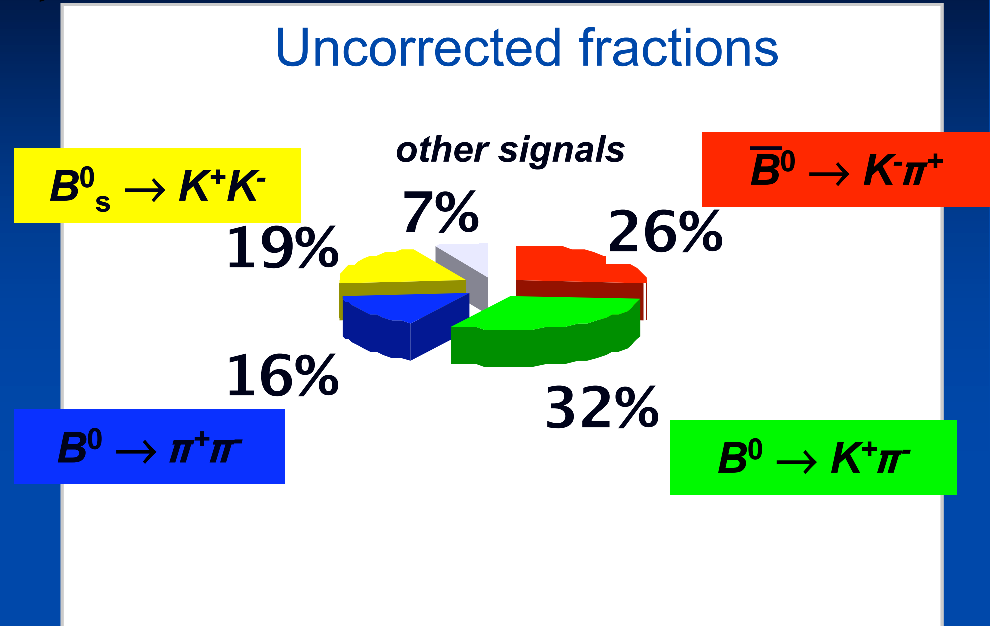


Signal shapes: from MC and analytic formula
Background shapes: from data sidebands

sign and bckg shapes from $D^0 \to K^- \pi^+$

Loose cuts, raw fit results





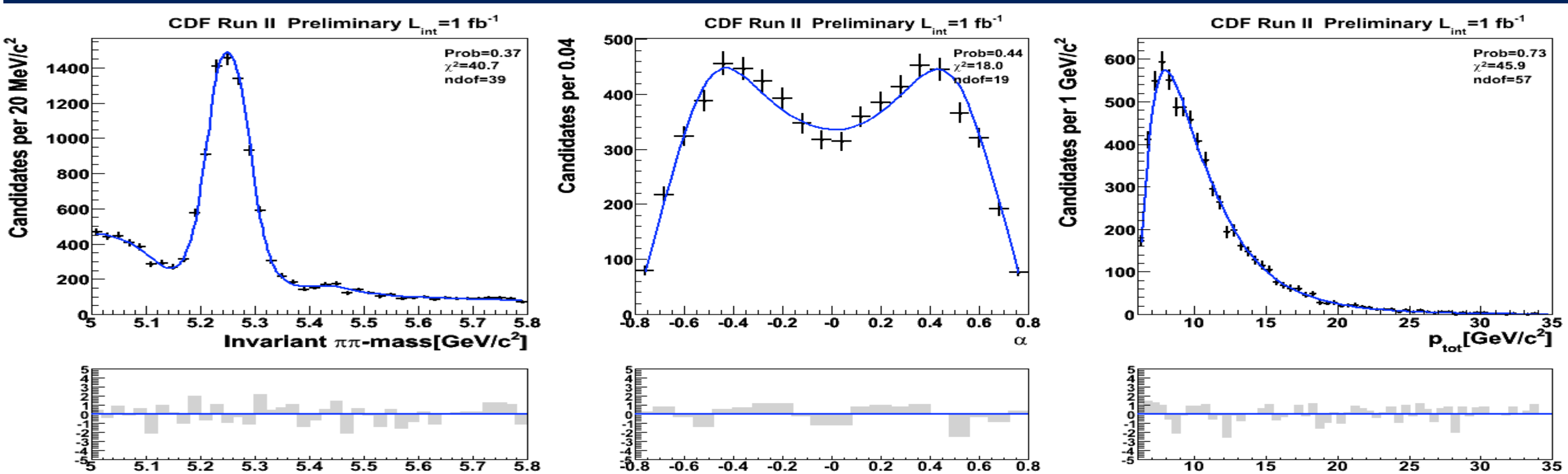
$B^0 \to h^+h'^-$ yields comparable to e^+e^-

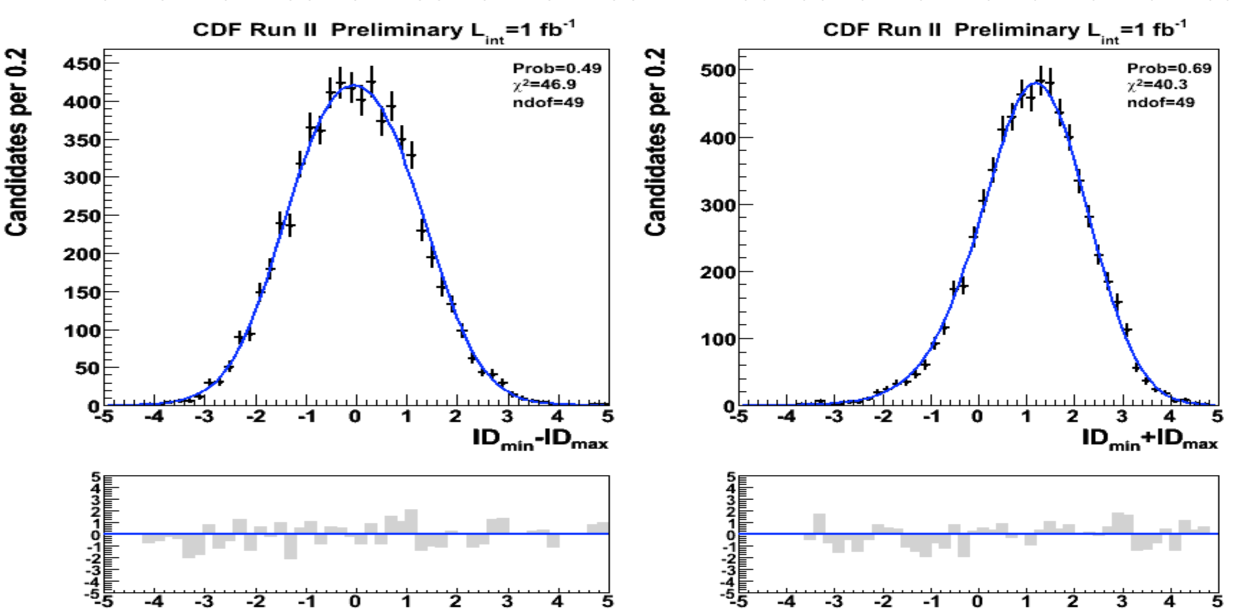
Good separation. Compare to $\sqrt{N}$ below:

parameter	fraction	yield	σ/σ_{ideal}
$B^0 \to \pi^+\pi^- + \text{c.c.}$	(0.160 ± 0.009)	1121 ± 63	1.8
$B^0 \to K^+\pi^- + \text{c.c.}$	(0.577 ± 0.010)	4045 ± 84	1.3
$B^0_s \to K^+K^- + \text{c.c.}$	(0.186 ± 0.009)	1307 ± 64	1.8

We only measure *relative* BRs and normalize to the $B^0 \to K^+\pi^-$ mode.

Fit projections





Further checks:

- Gaussian fit pulls
- PID-less fit agrees with regular fit
- Free-mass-scale fit agrees and returns mass shift

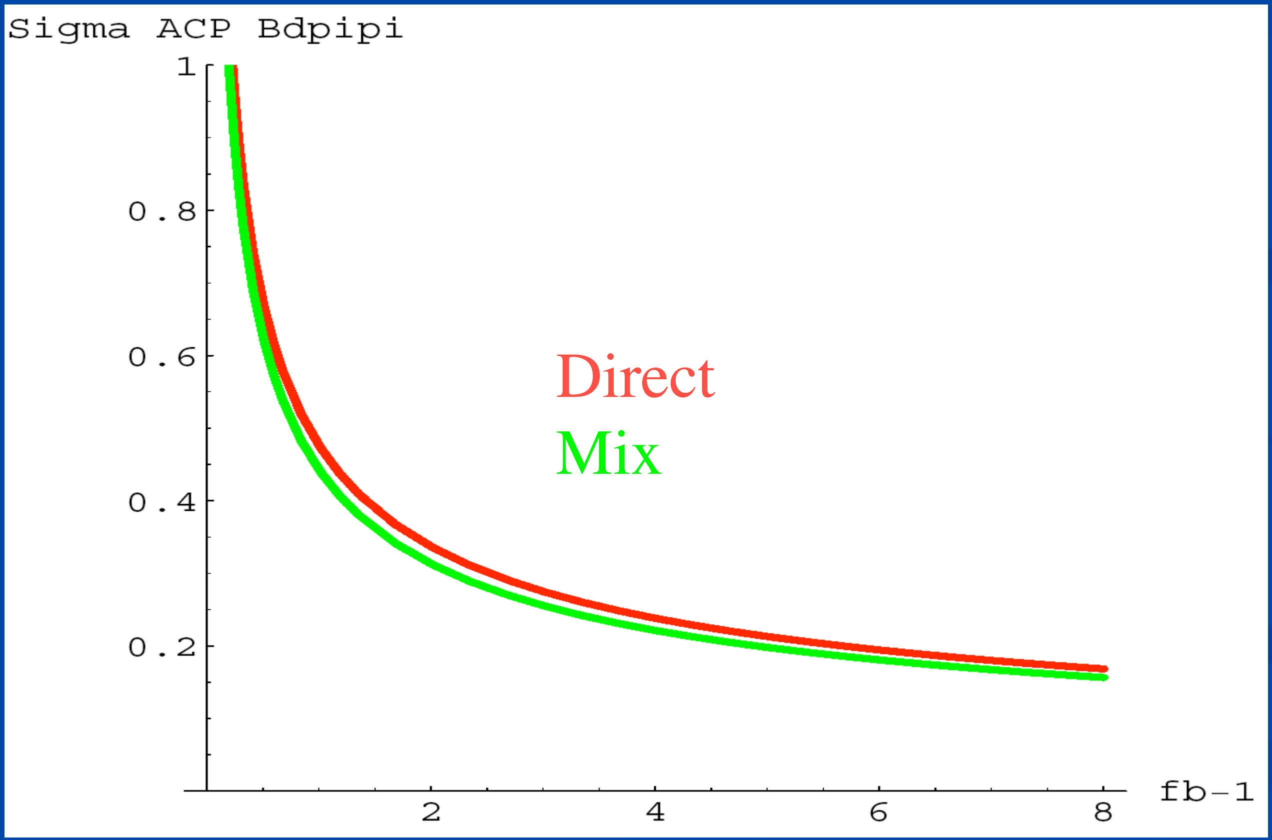
$$\delta = 0.2 \pm 0.6 \text{ MeV}/c^2$$

Results for known modes

BR($B^0 \rightarrow \pi^+\pi^-$)

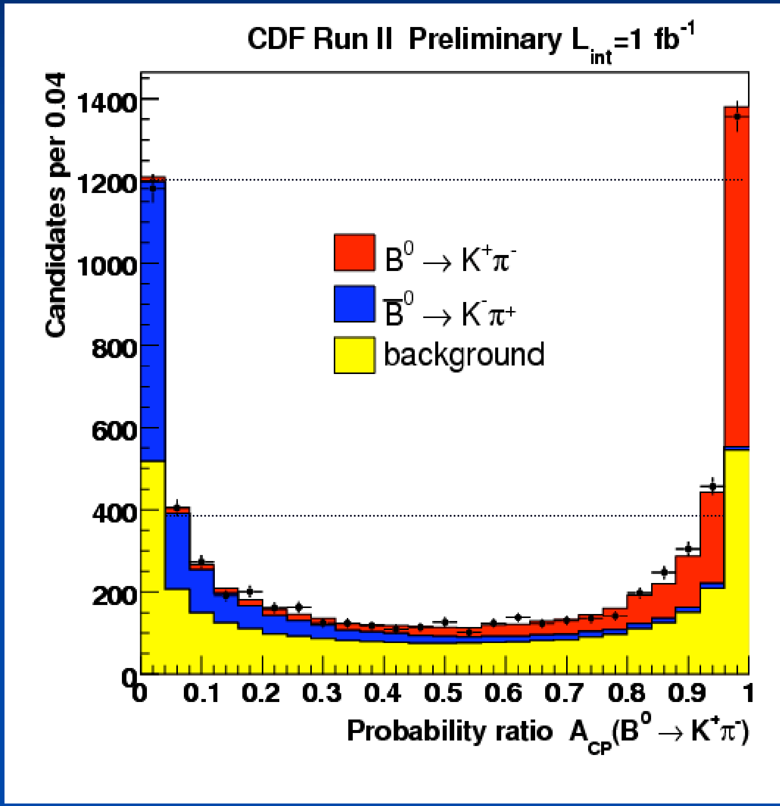
$$\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} = 0.259 \pm 0.017\ (stat.) \pm 0.016\ (syst.)$$

$$BR(B^0 \to \pi^+\pi^-) = (5.10 \pm 0.33\ (stat.) \pm 0.36\ (syst.)) \times 10^{-6}$$



- Precision measurements. systematic≅ statistics.
- Confirm previous results in a very different experimental setting
- Good yield, bright perspectives for time-dependent measurements: expect similar resolution to e+e- with full runII sample

Direct CP asymmetry $B^0 \rightarrow K^+\pi^-$



Large sample allows measuring DCPV

Plot of L(B0)/[L(Bbar)+L(B0)] shows the good separation achieved between B0 and Bbar (mass, alpha, dE/dx)

Significant raw asymmetry, good resolution:

$$A_{\mathrm{CP}}\Big|_{\mathrm{raw}} = \frac{N_{\mathrm{raw}}(\overline{B}^0 \rightarrow K^-\pi^+) - N_{\mathrm{raw}}(B^0 \rightarrow K^+\pi^-)}{N_{\mathrm{raw}}(\overline{B}^0 \rightarrow K^-\pi^+) + N_{\mathrm{raw}}(B^0 \rightarrow K^+\pi^-)} = -0.092 \pm 0.023$$

Correcting the raw A_{CP}

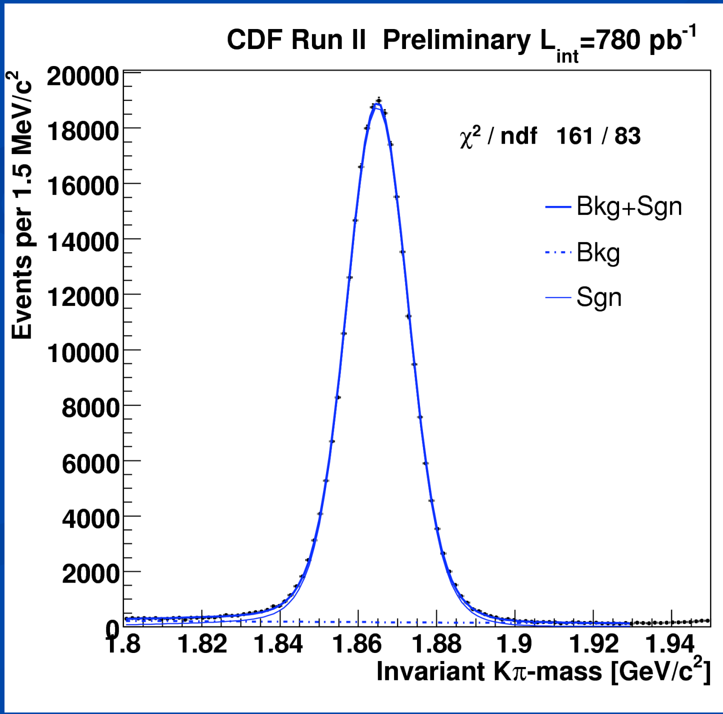
$$A_{CP}(B^0 \to K^+\pi^-) = \frac{N_{raw}(\overline{B}^0 \to K^-\pi^+)\cdot\frac{\varepsilon(K^+\pi^-)}{\varepsilon(K^-\pi^+)} - N_{raw}(B^0 \to K^+\pi^-)}{N_{raw}(\overline{B}^0 \to K^-\pi^+)\cdot\frac{\varepsilon(K^+\pi^-)}{\varepsilon(K^-\pi^+)} + N_{raw}(B^0 \to K^+\pi^-)}$$

Only the different K^+/K^- interaction rate with material matters. K^- has a larger hadronic cross section than K^+. Small (~0.6%) correction.

Huge sample of prompt $D^0 \to h^+h^-$ (15M). Using the *same code* of the B→hh fit and the assumption that the direct $A_{CP}(D^0 \to K\pi) \cong 0$ (SM) ⇒ measurement from the DATA of the efficiency ratio $\varepsilon(K^-\pi^+)/\varepsilon(K^+\pi^-)$:

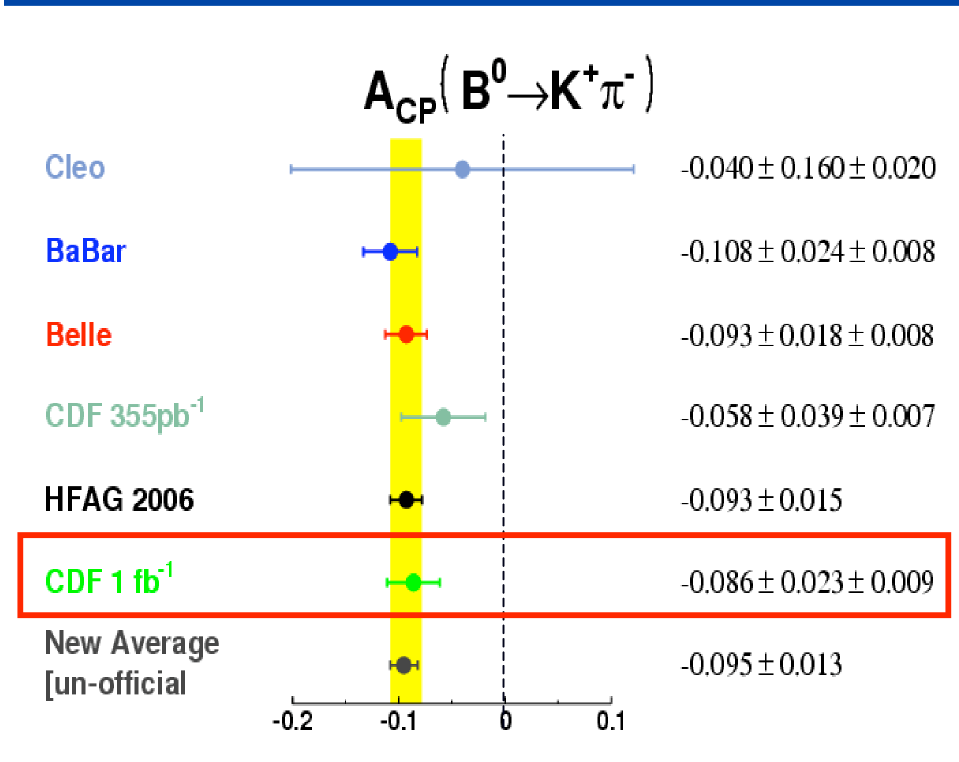
$$\boxed{\frac{\epsilon(K^+\pi^-)}{\epsilon(K^-\pi^+)} = 1.0131 \pm 0.0028\ (stat.).}$$

This agrees with an indipendent evaluation from simulation of CDF detector material



Results on $A_{CP}(B^0 \to K^+\pi^-)$

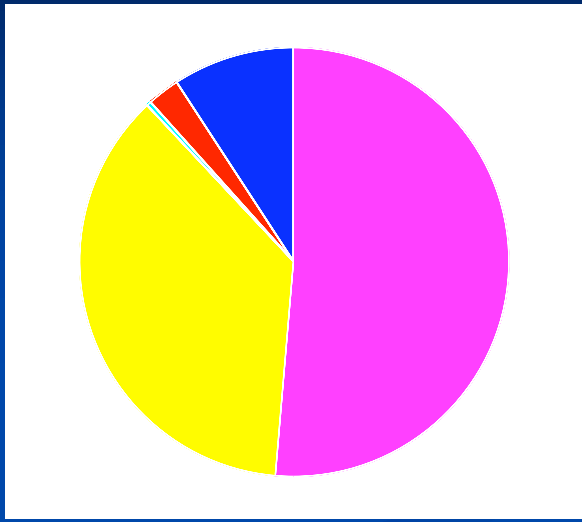
$$A_{CP} = \frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.086 \pm 0.023\ (stat.) \pm 0.009\ (syst.)$$



- ✓3.5σ effect. CDF agrees with e+e-
- ✓WA significance 6 σ →7 σ
- ✓Discrepancy with $A_{CP}(B^+ \to K^+\pi^0)$ increases to 4.9 sigma.
- ✓It has been argued that the constraint of equality is not reliable: a much more robust test exist, based on Bs->Kpi (more later).

Systematics $A_{CP}(B^0 \rightarrow K^+\pi^-)$

- dE/dx model (±0.0064);
- nominal *B*-meson masses input to the fit (±0.005);
- global mass scale;
- background charge-asymmetries (±0.001);
- background model (±0.003).



Total systematic uncertainty is 0.9%, compare with 2.3% statistical.

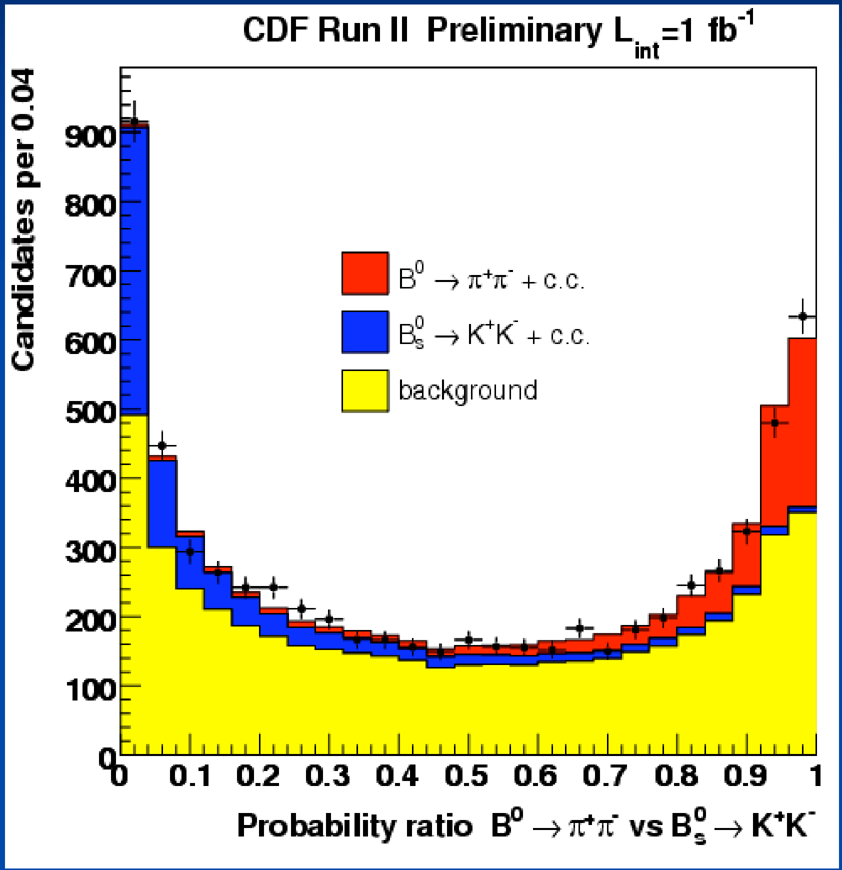
The dominant systematics is due to the dE/dx.

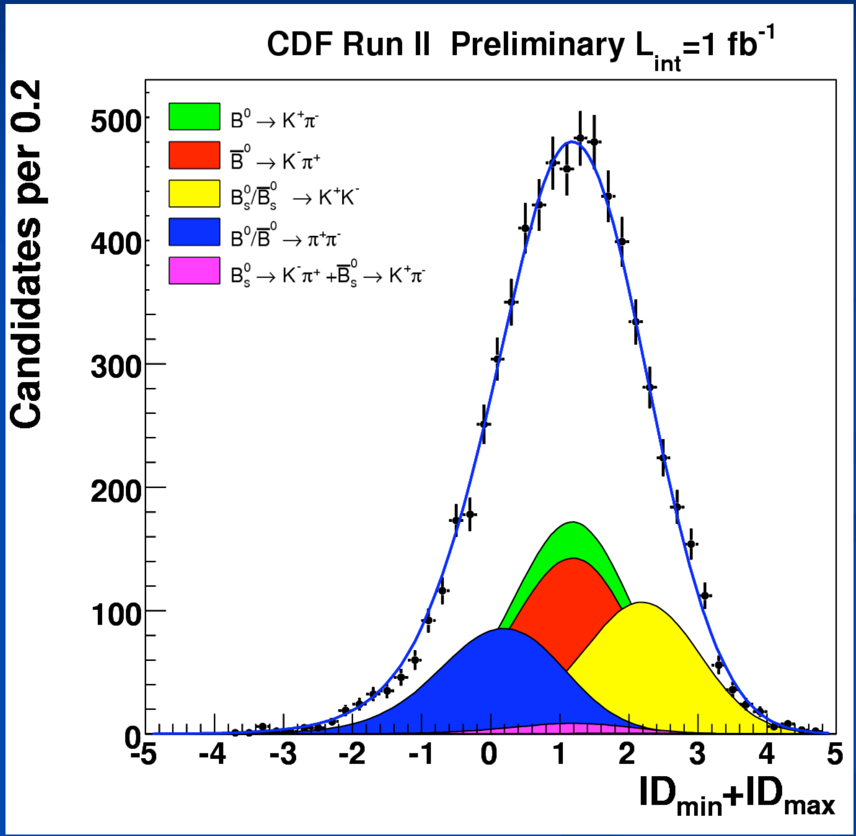
Additional crosscheck: measurement of $A_{CP}(D^0 \rightarrow K\pi)$ with dE/dx-only.
The discrepancy of two fits ($\cong$0.006) is within the quoted systematics.

Systematics can still decrease with larger calibration samples
Prospects for a runII CDF measurement with <1% uncertainty !

Separating $B^0_s \to K^+K^-$ from $B^0 \to \pi^+\pi^-$

PID separation $\pi\pi$/KK ≅2σ





parameter	fraction	yield
$B^0_s \to K^+K^- +$ c.c.	(0.186 ± 0.009)	$\boxed{1307 \pm 64}$

Large sample

Isolation cut efficiency

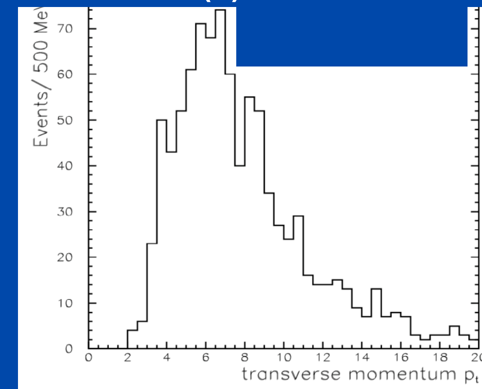
In order to normalize Bs Branching Fraction, need to know the relative efficiency.

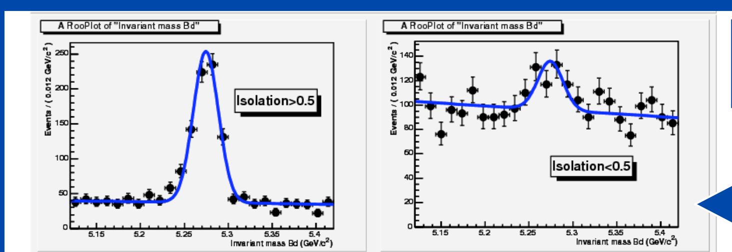
The Isolation cut may affect Bs and B0 differently. Use data to measure it (p_T – dependent)

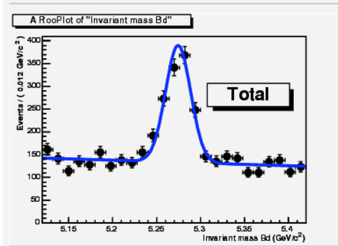
Need low-p_T samples: low edge of $p_T \sim 3$ GeV

Maximum Likelihood fit of yields in exclusive modes.

$p_T(B^0_{(s)} \to h^+ h'^-)$

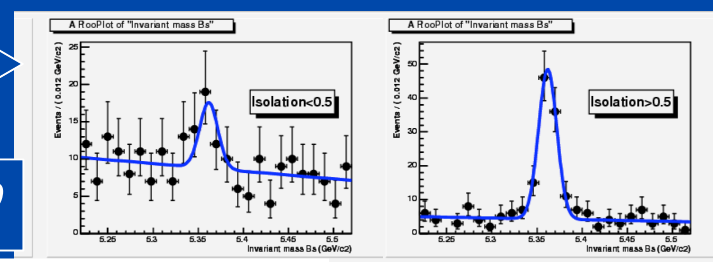


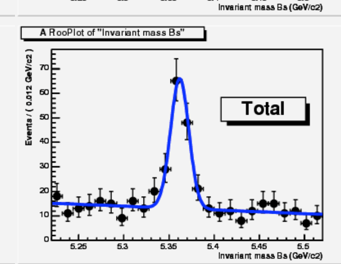




$B^0_s \to J/\psi\phi$

$B^0 \to J/\psi K^{*0}$





GeV/c	$\epsilon_{Iso}(B_d)$	$\epsilon_{Iso}(B_s)$	$\epsilon_{Iso}(B_d)/\epsilon_{Iso}(B_s)$
$p_T(B) < 6$	57.5 ± 9.7	70.1 ± 14.6	0.82 ± 0.22
$6 < p_T(B) < 10$	84.6 ± 2.4	84.8 ± 5.7	1.00 ± 0.08
$p_T(B) > 10$	93.8 ± 1.2	90.4 ± 2.8	1.04 ± 0.03

$BR(B^0_s \to K^+K^-)$

$$\frac{f_s \cdot BR(B^0_s \to K^+K^-)}{f_d \cdot BR(B^0 \to K^+\pi^-)} = 0.324 \pm 0.019\ (stat.) \pm 0.041\ (syst.)$$

$$\boxed{BR(B^0_s \to K^+K^-) = (24.4 \pm 1.4\ (stat.) \pm 4.6\ (syst.)) \times 10^{-6}}$$

Conservative systematics now , but soon systematics$\cong$ statistics.

Naively : $BR(B^0_s \to K^+K^-) \cong BR(B^0 \to K^+\pi^-) \cong 20\ 10^{-6}$

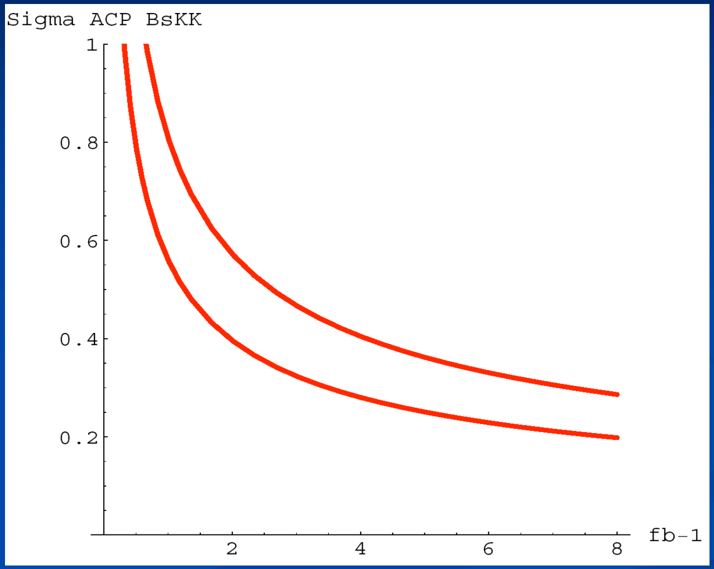
QCD sum rules predict large SU(3) breaking $BR(B^0_s \to K^+K^-) \cong 35\ 10^{-6}$
[Khodjamirian et al. PRD68:114007, 2003; Buras et al, Nucl. Phys. B697, 133,2004]

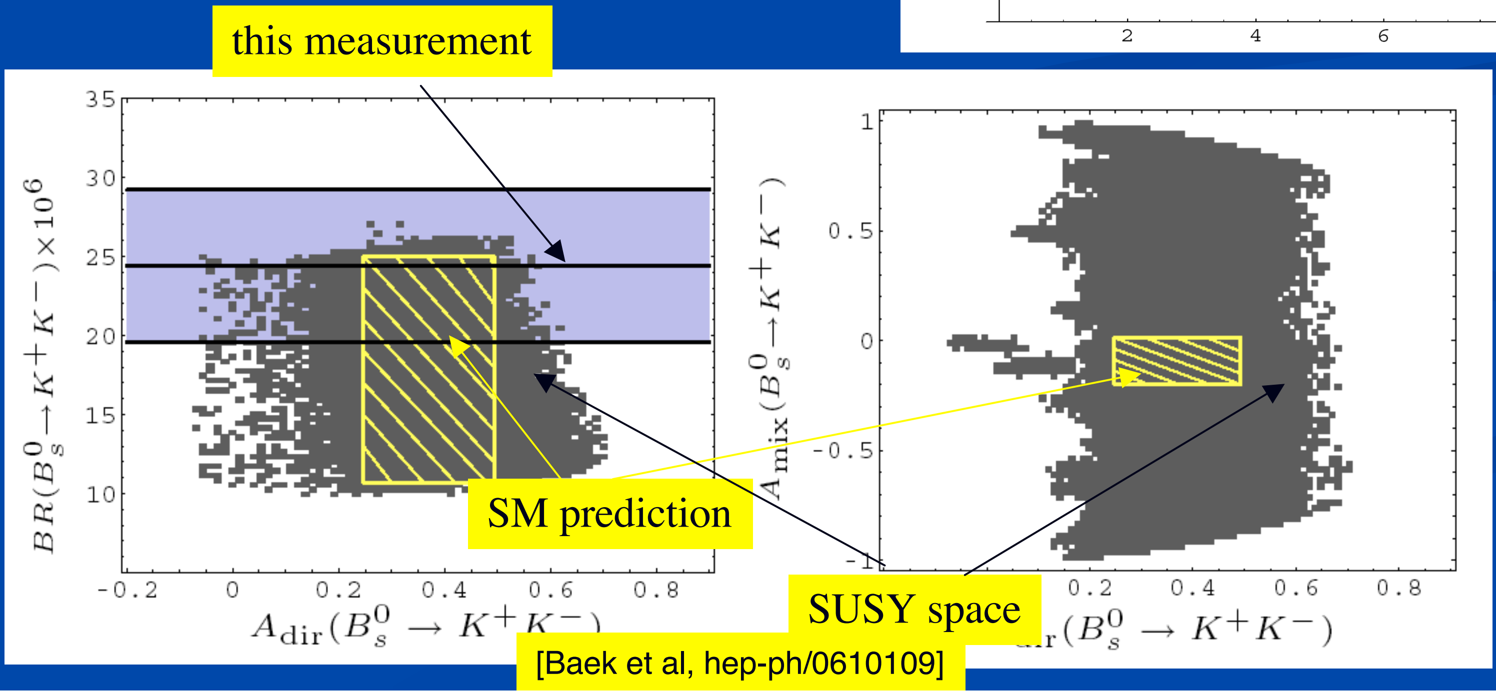
More recently, 1/mb corrections give lower values again:
$BR(B^0_s \to K^+K^-)\ 20 \pm 8 \pm 4\ 10^{-6}$
[Descotes-Genon et al. PRL97, 061801, 2006]

Prospects for $A_{CP}(B^0_s \rightarrow K^+K^-)$

The large available sample allows expecting $\sigma(A_{CP})$ ~0.2 with runII sample

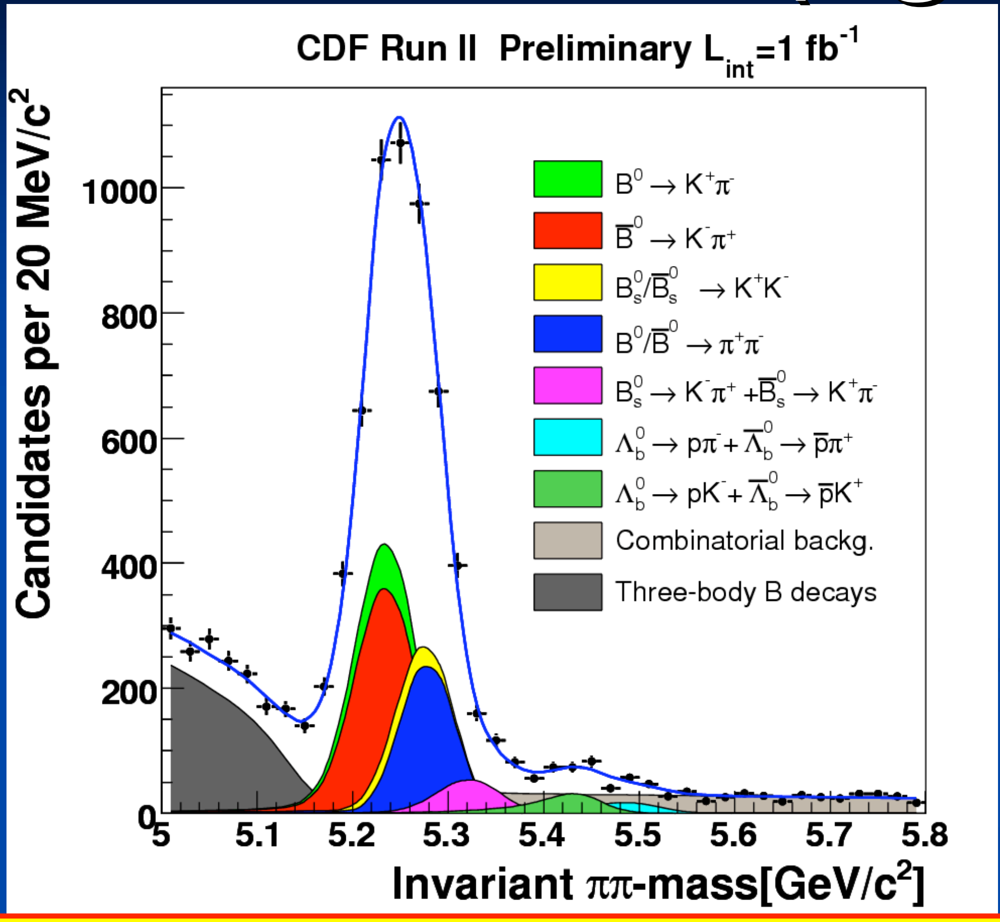
This allows searches for new physics. See below a recent work quoting the present measurement about SUSY search





Search for new modes

Rare modes search (tight cuts)



3 new rare modes observed

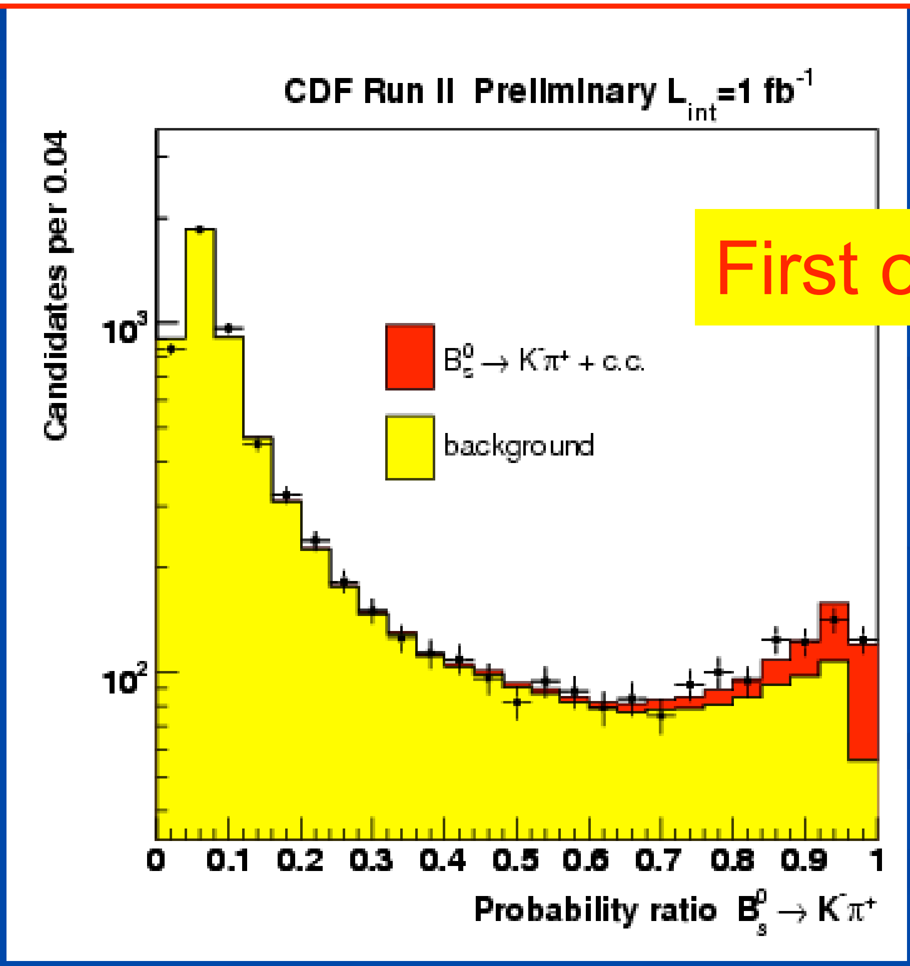
$$N_{\rm raw}(B^0_s \to K^-\pi^+) = 230 \pm 34\ (stat.) \pm 16\ (syst.)$$ **(8σ)**

$$N_{\rm raw}(\Lambda^0_b \to p\pi^-) = 110 \pm 18\ (stat.) \pm 16\ (syst.)$$ **(6σ)**

$$N_{\rm raw}(\Lambda^0_b \to pK^-) = 156 \pm 20\ (stat.) \pm 11\ (syst.)$$ **(11σ)**

$B^0_s \to K^-\pi^+$

$$N_{\rm raw}(B^0_s \to K^-\pi^+) \;=\; 230 \pm 34\ (stat.) \pm 16\ (syst.)$$



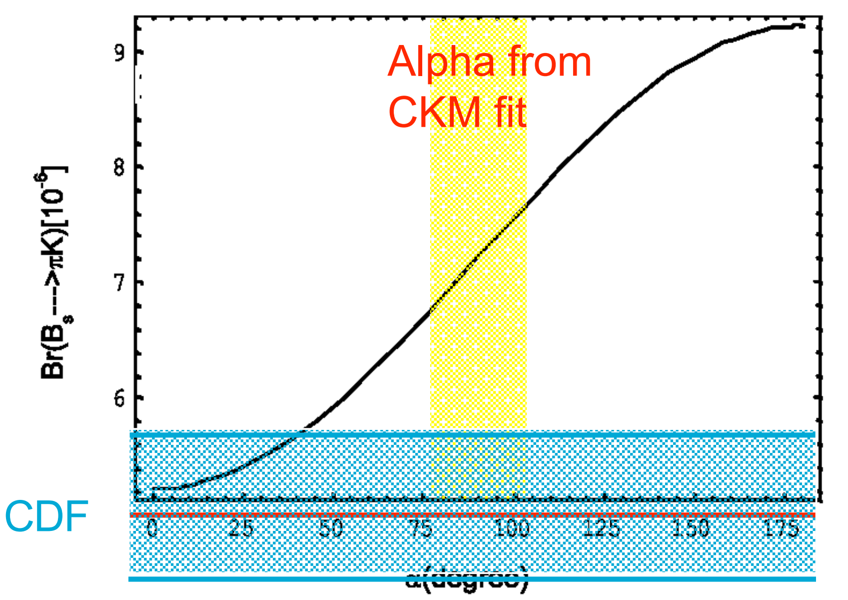
First observation(**8σ**)

$BR(B^0_s \to K^-\pi^+)$

$$\frac{f_s \cdot BR(B^0_s \to K^-\pi^+)}{f_d \cdot BR(B^0 \to K^+\pi^-)} = 0.066 \pm 0.010\ (stat.) \pm 0.010\ (syst.)$$

$$\boxed{BR(B^0_s \to K^-\pi^+) = (5.0 \pm 0.75\ (stat.) \pm 1.0\ (syst.)) \times 10^{-6}}$$

Previous limit (CDF) < 5.4 @90% CL



[Yu, Li, Yu, Phys.Rev. D71 (2005) 074026]

PREDICTIONS:

$[7 \div 10] \cdot 10^{-6}$ [Beneke&Neubert NP B675, 333(2003)]

$[6 \div 10] \cdot 10^{-6}$ [Yu, Li, Yu, PRD71: 074026 (2005)]

$(4.9 \pm 1.8) \cdot 10^{-6}$ [Williamson,Zupan:PRD74(2006)014003

Large sensitivity to angle α/γ

[Gronau, Rosner, Phys. Lett. B 482, 71 (2000)]

[Yu, Li, Yu, Phys.Rev. D71 (2005) 074026]

DCPV $B^0_s \to K^-\pi^+$

This decay offers a unique opportunity of investigating the source of CP violation, and the reason for the discrepancy observed in Bd:

"Is observed direct CP violation in $B^0 \to K^+\pi^-$ due to new physics ? Check standard Model prediction of equal violation in $B^0_s \to K^-\pi^+$ "
[Lipkin, Phys. Lett. B621:126, .2005],
[Gronau Rosner Phys.Rev. D71 (2005) 074019].

$$|A(B_s \to \pi^+ K^-)|^2 - |A(\bar{B}_s \to \pi^- K^+)|^2 = |A(\bar{B}_d \to \pi^+ K^-)|^2 - |A(B_d \to \pi^- K^+)|^2$$

This comparison of $B^0 \to K^+\pi^-$ and $B^0_s \to K^-\pi^+$ is a probe of NP in CP violation based on really minimal assumption. Currently unique to CDF.

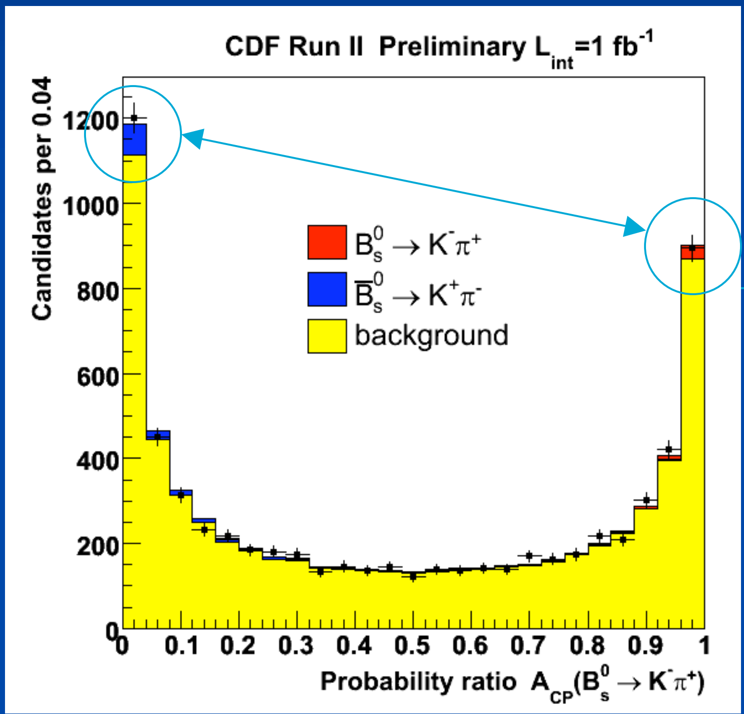
$$\frac{A_{CP}(B_s \to K^-\pi^+)}{A_{CP}(B_d \to K^+\pi^-)} = \frac{BR(B_d \to K^+\pi^-)}{BR(B_s \to K^-\pi^+)}$$

From our measured low BR, expect Large asymmetry $\cong$ **37%**

DCPV $B^0_s \to K^-\pi^+$

$$A_{CP} = \frac{N(\overline{B}^0_s \to K^+\pi^-) - N(B^0_s \to K^-\pi^+)}{N(\overline{B}^0_s \to K^+\pi^-) + N(B^0_s \to K^-\pi^+)} = 0.39 \pm 0.15\ (stat.) \pm 0.08\ (syst.)$$

2.5 σ



$$\frac{|A(\bar{B}_d \to \pi^+ K^-)|^2 - |A(B_d \to \pi^- K^+)|^2}{|A(B_s \to \pi^+ K^-)|^2 - |A(\bar{B}_s \to \pi^- K^+)|^2}$$

= 0.84 ± 0.42(stat.) ± 0.15(syst.) (SM =1)

First measurement of DCPV in the Bs

Sign and magnitude agree with SM predictions within errors

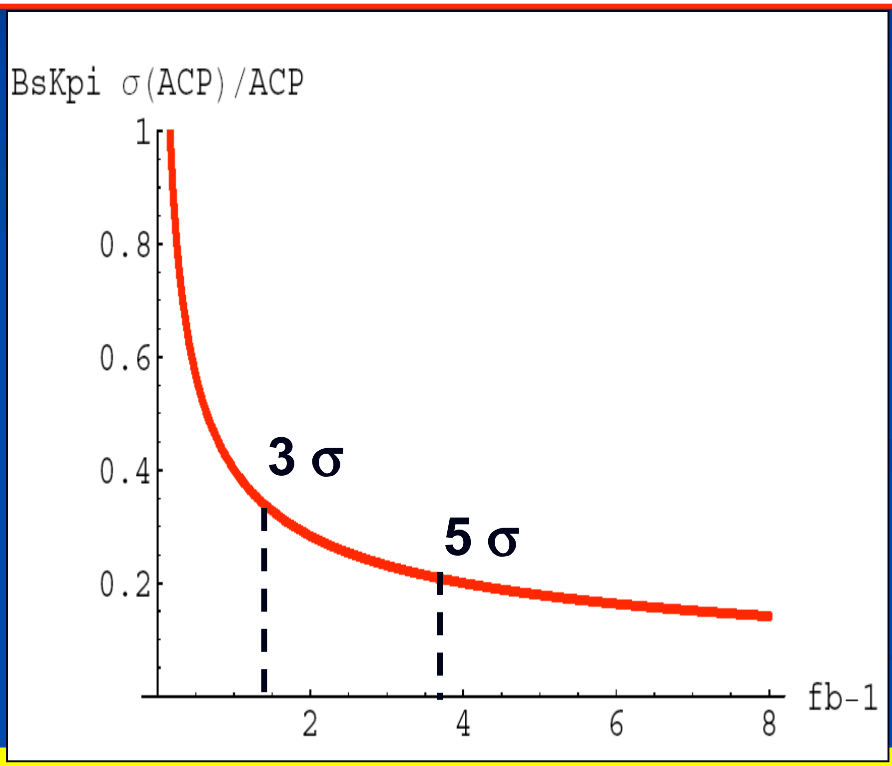
$\Rightarrow$ no evidence for exotic sources of CP violation (yet)

Very interesting to pursue with more data !

DCPV $B^0_s \to K^-\pi^+$

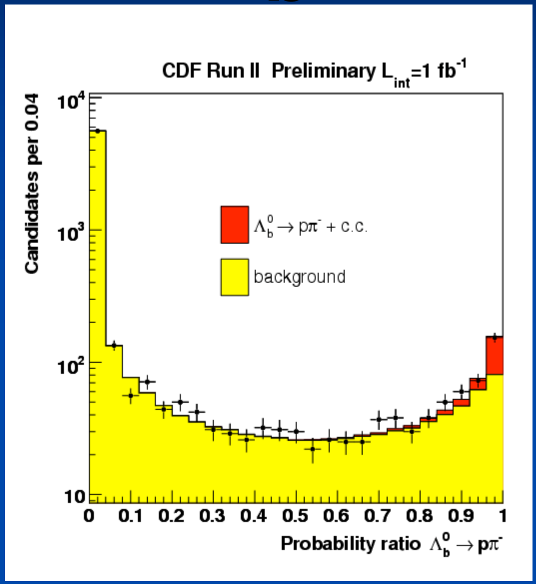
$$A_{CP} = \frac{N(\overline{B}^0_s \to K^+\pi^-) - N(B^0_s \to K^-\pi^+)}{N(\overline{B}^0_s \to K^+\pi^-) + N(B^0_s \to K^-\pi^+)} = 0.39 \pm 0.15\ (stat.) \pm 0.08\ (syst.)$$

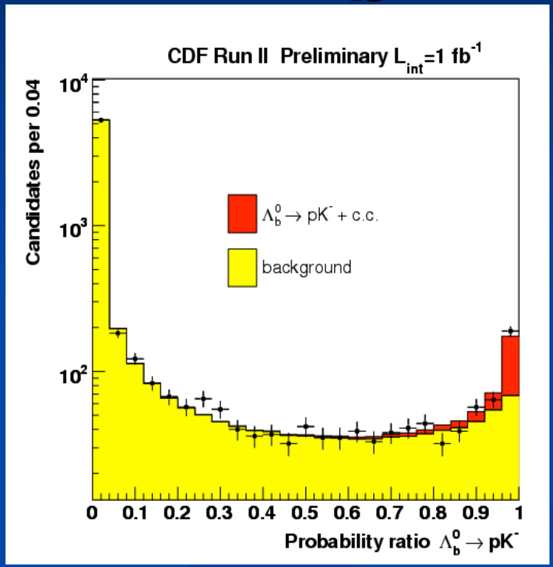
2.5 σ



First measurement of DCPV in the Bs
Sign and magnitude agree with SM predictions within errors
⇒ no evidence for exotic sources of CP violation (yet)
Very interesting to pursue with more data !

First observation of $\Lambda^0_b \to p\pi^-$ and $\Lambda^0_b \to pK^-$





$$N_{\rm raw}(\Lambda_b^0 \to pK^-) = 156 \pm 20\ (stat.) \pm 11\ (syst.)$$ **11 σ**

$$N_{\rm raw}(\Lambda_b^0 \to p\pi^-) = 110 \pm 18\ (stat.) \pm 16\ (syst.)$$ **6 σ**

$$\frac{BR(\Lambda_b^0 \to p\pi^-)}{BR(\Lambda_b^0 \to pK^-)} = 0.66 \pm 0.14\ (stat.) \pm 0.08\ (syst.)$$

See for the first time a charmless decay of a B *barion*

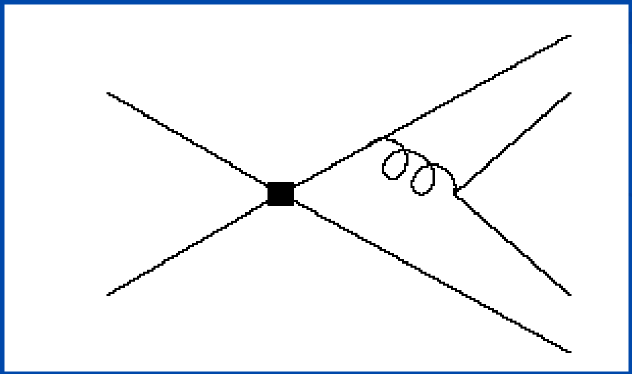
Ratio of BR in agreement with predictions (0.60-0.62)

[Mohanta et al. Phys.Rev. D63 (2001) 074001]

Individual BR and ACP measurements in progress

Even rarer modes:

Weak annihilation



Pure-annihilation modes

- All final-state quarks different from initial state quarks. $\Rightarrow$only via annihilation-type diagrams
- Not yet observed. Small BR, with large uncertainties.
- Depends on hard-to-predict hadronic parameters $\Rightarrow$ large source of uncertainty in calculations.
- CDF can look for $B_s \to \pi^+\pi^-$ in addition to $B_d \to K^+K^-$,

  B_s is expected larger by x3-x4.

• To extract annihilation hadronic parameters, need BOTH measurements:

$$\frac{1}{\epsilon}\left[\frac{\mathrm{BR}(B_d \to K^+K^-)}{\mathrm{BR}(B_s \to \pi^+\pi^-)}\right]\frac{\tau_{B_s^0}}{\tau_{B_d^0}} = \frac{1 + 2\varrho_{\mathcal{PA}}\cos\vartheta_{\mathcal{PA}}\cos\gamma + \varrho_{\mathcal{PA}}^2}{\epsilon^2 - 2\epsilon\varrho_{\mathcal{PA}}\cos\vartheta_{\mathcal{PA}}\cos\gamma + \varrho_{\mathcal{PA}}^2}$$

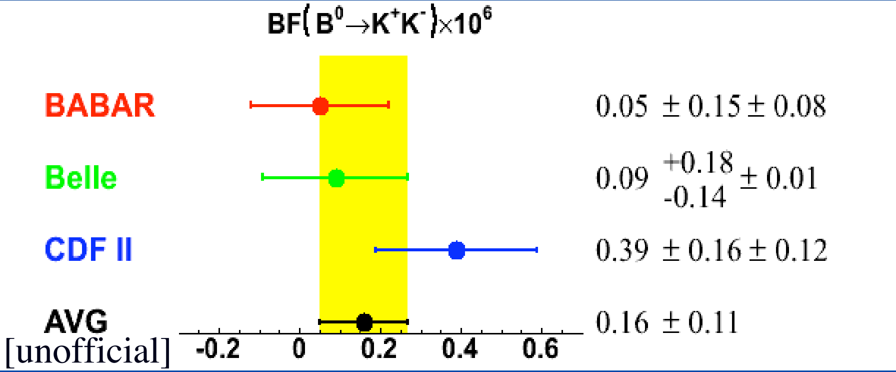
[Buras et al., Nucl.Phys. B697 (2004) 133]

Results on $B^0_s \to \pi^+\pi^-$ and $B^0 \to K^+K^-$

1.5 σ

$$BR(B^0 \to K^+K^-) = (0.39 \pm 0.16\ (stat.) \pm 0.12\ (syst.)) \times 10^{-6}$$

($< 0.7 \cdot 10^{-6}$ @ 90% CL)



New WA : 0.16 ± 0.11 [speaker's calculation]

Expectations $[0.007 \div 0.08] \cdot 10^{-6}$

[Beneke&Neubert NP B675, 333(2003)]

$\Longrightarrow$ now in the region of interest

1.5 σ

$$BR(B^0_s \to \pi^+\pi^-) = (0.53 \pm 0.31\ (stat.) \pm 0.40\ (syst.)) \times 10^{-6}$$

Current best limit

$<1.36 \cdot 10^{-6}$ @ 90% CL

Expectations: $[0.024 \div 0.16] \cdot 10^{-6}$ [Beneke&Neubert NP B675, 333(2003)]

$0.42 \pm 0.06 \cdot 10^{-6}$ [Li et al. hep-ph/0404028]

We have reached the interesting region for these channels.
A signal may be just around the corner

Summary

- Large set of measurements
- First observation of $B^0_s \rightarrow K^- \pi^+$ mode
- First observation of B-baryon modes $\Lambda_b \rightarrow pK$ / $p\pi$ m
- First measurement of DCPV in B^0_s:
  $A_{CP}(B^0_s \rightarrow K^- \pi^+)$ at 2.5σ, in agreement with SM
- Precision $A_{CP}(B^0 \rightarrow K^+ \pi^-)$ confirms B-factories results. Increase significance of DCPV to 7σ, and 4.9σ discrepancy with B^+
- Updated $BR(B^0_s \rightarrow K^+ K^-)$ disfavors large U-spin breaking, agrees with latest predictions
- Updated results on annihilation: $B^0 \rightarrow K^+ K^-$ $B^0_s \rightarrow \pi^+ \pi^-$

CDF is contributing fresh new results in Charmless two-body decays of the B^0, plus has unique results on B^0_s and baryons. Much more data and more measurements are expected, including time-dependent.

$B^0 \to hh$ people

S. Donati, D. Tonelli, G. Volpi, M. Morello, G.P.

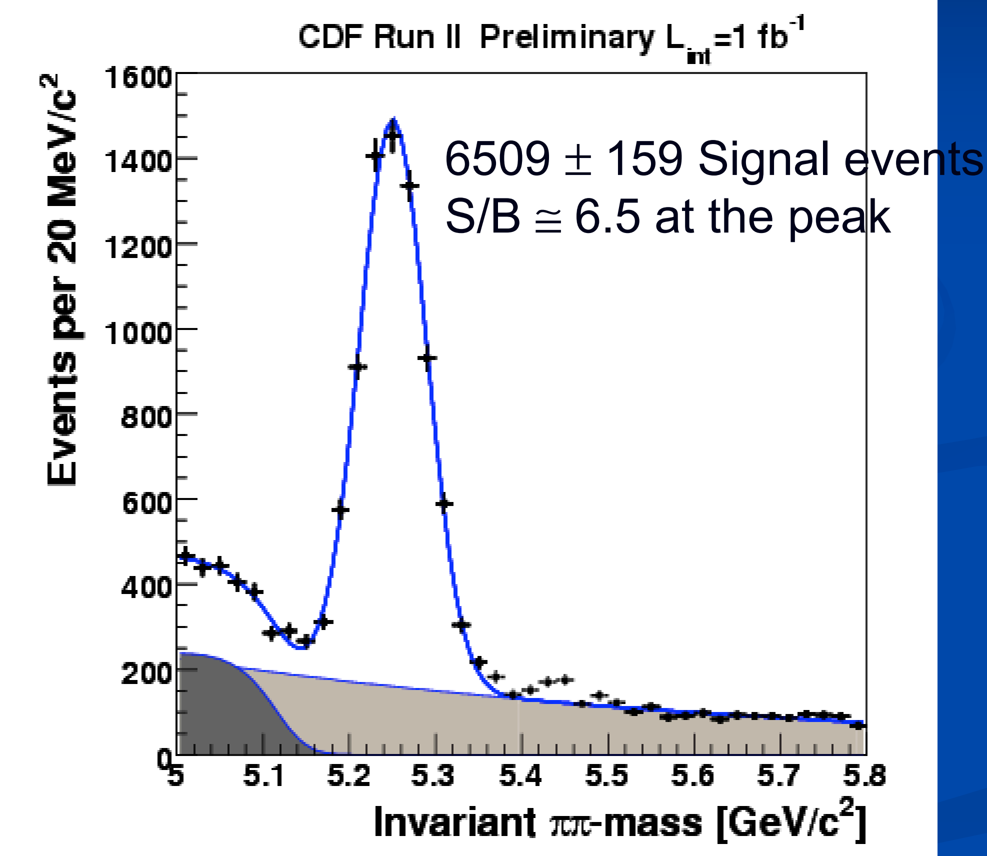
Backup

DATA SAMPLE 1fb^{-1}

Cuts optimized for ACP(BdKpi)

variable	cut
# axial COT SL	$\geq$ 2(5 hits)
# stereo COT SL	$\geq$ 2(5 hits)
# $r-\phi$ SVXII hits	≥ 3
tracking algorithm	sil. r-ϕ and 90°z hits
$\mid \eta \mid$	≤ 1
p_T	$\geq$ 2 GeV/c
$p_T(1)+p_T(2)$	$\geq$ 5.5 GeV/c
$q(1)\cdot q(2)$	< 0
$\Delta\phi$	$\geq 20°$
$\Delta\phi$	$\leq 135°$
$\mid d_0 \mid$	$\geq 100\ \mu m$
$\mid d_0 \mid$	$\leq$ 1 mm
$d_0(1)\cdot d_0(2)$	<0 cm^2

variable	cut
$\mid \eta(B) \mid$	≤ 1
$\mid d_0(B) \mid$	$\leq 80\ \mu m$
$L_{xy}(B)$	$\geq 300\ \mu m$
$\chi^2_{3D}(B)$	≤ 7
isolation $I_{R=1}$	≥ 0.5

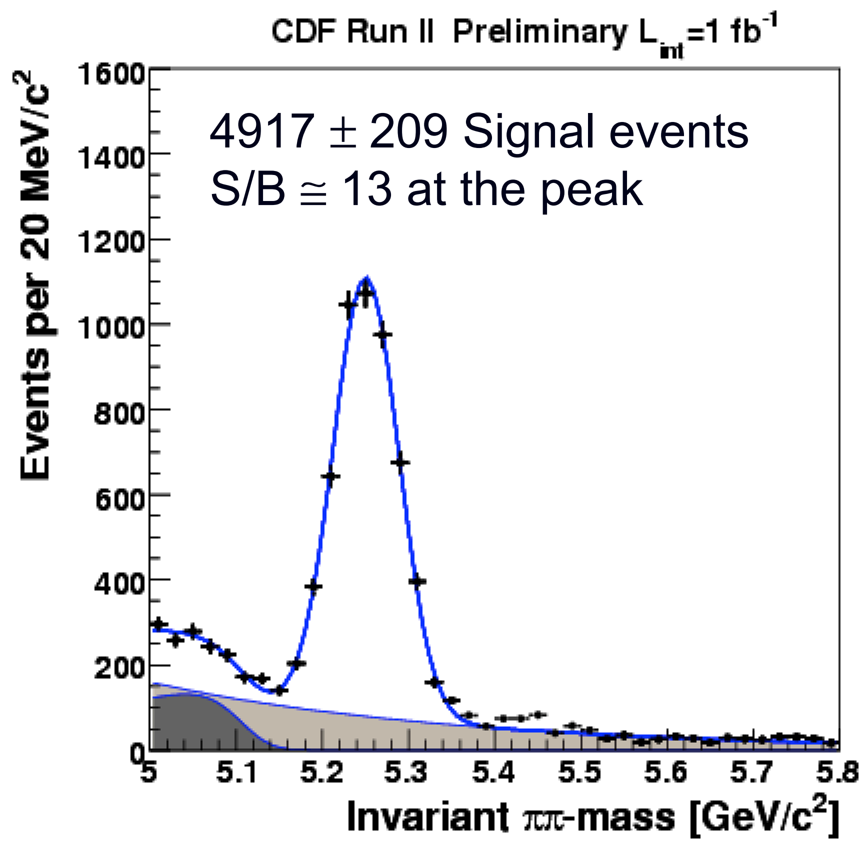


DATA SAMPLE $1fb^{-1}$

Cuts optimized for rare modes

variable	cut
# axial COT SL	$\geq$ 2(5 hits)
# stereo COT SL	$\geq$ 2(5 hits)
# $r-\phi$ SVXII hits	≥ 3
tracking algorithm	sil. r-ϕ and 90°z hits
$\mid \eta \mid$	≤ 1
p_T	$\geq$ 2 GeV/c
$p_T(1)+p_T(2)$	$\geq$ 5.5 GeV/c
$q(1)\cdot q(2)$	< 0
$\Delta\phi$	$\geq 20°$
$\Delta\phi$	$\leq 135°$
$\mid d_0 \mid$	$\geq 120\ \mu m$
$\mid d_0 \mid$	$\leq$ 1 mm
$d_0(1)\cdot d_0(2)$	$<0\ cm^2$

variable	cut
$\mid \eta(B) \mid$	≤ 1
$\mid d_0(B) \mid$	$\leq 60\ \mu m$
$L_{xy}(B)$	$\geq 350\ \mu m$
$\chi^2_{3D}(B)$	≤ 5
isolation $I_{R=1}$	≥ 0.525



ACP cuts: physical parameters

$$A_{\mathrm{CP}} = \frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.086 \pm 0.023\ (stat.) \pm 0.009\ (syst.)$$

$$\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} = 0.259 \pm 0.017\ (stat.) \pm 0.016\ (syst.)$$

$$\frac{f_s \cdot BR(B_s^0 \to K^+K^-)}{f_d \cdot BR(B^0 \to K^+\pi^-)} = 0.324 \pm 0.019\ (stat.) \pm 0.041\ (syst.)$$

With HFAG 2006:

$$BR(B^0 \to \pi^+\pi^-) = (5.10 \pm 0.33\ (stat.) \pm 0.36\ (syst.)) \times 10^{-6}$$

$$BR(B_s^0 \to K^+K^-) = (24.4 \pm 1.4\ (stat.) \pm 4.6\ (syst.)) \times 10^{-6}$$

BsKpi cuts: physical parameters (1)

$$
\begin{aligned}
A_{\mathrm{CP}} = \frac{N(\overline{B}^0_s \to K^+\pi^-) - N(B^0_s \to K^-\pi^+)}{N(\overline{B}^0_s \to K^+\pi^-) + N(B^0_s \to K^-\pi^+)} &= 0.39 \pm 0.15\ (stat.) \pm 0.08\ (syst.) \\
\frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0_s \to K^+\pi^-) - N(B^0_s \to K^-\pi^+)} &= -3.21 \pm 1.60\ (stat.) \pm 0.39 (sys.) \\
N_{\mathrm{raw}}(B^0_s \to K^-\pi^+) &= 230 \pm 34\ (stat.) \pm 16\ (syst.) \\
\frac{f_s \cdot BR(B^0_s \to K^-\pi^+)}{f_d \cdot BR(B^0 \to K^+\pi^-)} &= 0.066 \pm 0.010\ (stat.) \pm 0.010\ (syst.)
\end{aligned}
$$

With HFAG 2006:

$$
BR(B^0_s \to K^-\pi^+) = (5.0 \pm 0.75\ (stat.) \pm 1.0\ (syst.)) \times 10^{-6}
$$

BsKpi cuts: physical parameters (2)

$$N_{\text{raw}}(B_s^0 \to \pi^+\pi^-) \quad = \quad 26 \pm 16\ (stat.) \pm 14\ (syst.)$$

$$N_{\text{raw}}(B^0 \to K^+K^-) \quad = \quad 61 \pm 25\ (stat.) \pm 35\ (syst.)$$

$$\frac{f_s \cdot BR(B_s^0 \to \pi^+\pi^-)}{f_d \cdot BR(B^0 \to K^+\pi^-)} \quad = \quad 0.007 \pm 0.004\ (stat.) \pm 0.005\ (syst.)$$

$$\frac{BR(B^0 \to K^+K^-)}{BR(B^0 \to K^+\pi^-)} \quad = \quad 0.020 \pm 0.008\ (stat.) \pm 0.006\ (syst.)$$

With HFAG 2006:

$$BR(B^0 \to K^+K^-) \quad = \quad (0.39 \pm 0.16\ (stat.) \pm 0.12\ (syst.)) \times 10^{-6}$$

$$BR(B^0 \to K^+K^-) \quad \in \quad [0.1 - 0.7] \cdot 10^{-6}\ @\ 90\%\ C.L.$$

$$BR(B_s^0 \to \pi^+\pi^-) \quad = \quad (0.53 \pm 0.31\ (stat.) \pm 0.40\ (syst.)) \times 10^{-6}$$

$$BR(B_s^0 \to \pi^+\pi^-) \quad < \quad 1.36 \cdot 10^{-6}\ @\ 90\%\ C.L.$$

BsKpi cuts: physical parameters (3)

$$N_{\mathrm{raw}}(\Lambda_b^0 \to pK^-) = 156 \pm 20 \ (stat.) \pm 11 \ (syst.)$$

$$N_{\mathrm{raw}}(\Lambda_b^0 \to p\pi^-) = 110 \pm 18 \ (stat.) \pm 16 \ (syst.)$$

$$\frac{BR(\Lambda_b^0 \to p\pi^-)}{BR(\Lambda_b^0 \to pK^-)} = 0.66 \pm 0.14 \ (stat.) \pm 0.08 \ (syst.)$$

Systematics: $A_{CP}(B^0 \to K^+\pi^-)$

source	shift wrt central fit
mass scale	0.0004
asymmetric momentum-p.d.f	0.0001
dE/dx	0.0064
input masses	0.0054
combinatorial background model	0.0027
momentum background model	0.0007
MC statistics	–
charge asymmetry	0.0014
$\Delta\Gamma_s/\Gamma_s$ Standard Model	–
lifetime	–
isolation efficiency	–
XFT-bias correction	–
TOTAL (sum in quadrature)	**0.009**

Systematics

$B^0 \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$

$$\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} \qquad \frac{f_s \cdot BR(B^0_s \to K^+K^-)}{f_d \cdot BR(B^0 \to K^+\pi^-)}$$

source	shift wrt central fit	shift wrt central fit
mass scale	0.0036	0.0034
asymmetric momentum-p.d.f	0.0006	0.0030
dE/dx	0.0129	0.0107
input masses	0.0050	0.0050
combinatorial background model	0.0020	0.0020
momentum background model	0.0010	0.0060
MC statistics	0.0011	0.0012
charge asymmetry	–	–
$\Delta\Gamma_s/\Gamma_s$ Standard Model	–	0.0060
lifetime	–	0.0060
isolation efficiency	–	0.0370
XFT-bias correction	0.0050	0.0080
TOTAL (sum in quadrature)	**0.0165**	**0.0413**

Isolation efficiency $\varepsilon(B^0)/\varepsilon(B^0_s)$ from the data using 180 pb^{-1}

$A_{CP}(B^0 \to K^+\pi^-)$ cuts: other fit parameters

Combinatorial background

parameter	value
f_{π^+} (combinatorial)	0.545 ± 0.017
f_{e^+} (combinatorial)	0.036 ± 0.005
f_p (combinatorial)	0.080 ± 0.025
f_{K^+} (combinatorial)	0.337 ± 0.031
f_{π^-} (combinatorial)	0.533 ± 0.018
f_{e^-} (combinatorial)	0.030 ± 0.005
$f_{\bar{p}}$ (combinatorial)	0.132 ± 0.027
f_{K^-} (combinatorial)	0.304 ± 0.033

$B \to 3$body background

fraction of physics bckg (ARGUS norm.)	0.197 ± 0.016
ARGUS cut-off [GeV/c^2]	5.135 ± 0.001
ARGUS shape	8.467 ± 3.45
f_π (ARGUS)	0.728 ± 0.027
f_K (ARGUS)	0.272 ± 0.027
background fraction	0.481 ± 0.008
c_1 (background shape)	-1.221 ± 0.124

Significance Table

(Statistical + systematic)

raw yield ± stat. from fit on data

systematic error

mode	yield	TOY stat. $(f=0)$	syst.	Sign.(TOY stat.$(f=0)$ + syst.)
$B^0 \to K^+K^-$	61 ± 25	21	35	1.5σ
$B_s^0 \to \pi^+\pi^-$	26 ± 16	11	14	1.5σ
$B_s^0 \to K^-\pi^+$	230 ± 34	23	16	8.2σ
$\Lambda_b^0 \to p\pi^-$	110 ± 18	9	16	5.9σ
$\Lambda_b^0 \to pK^-$	156 ± 20	8	11	11.5σ

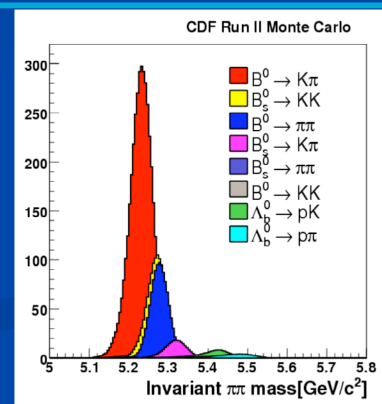
statistical uncertainty from pseudo experiments where the fractions of rare modes are fixed =0.

statistical error from the pseudo-experiment + systematic error. (Sum in quadrature).

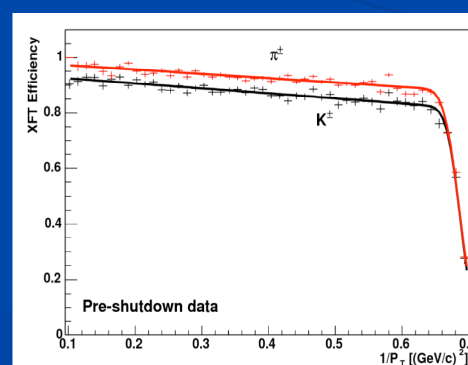
B^0_$\pi^+\pi^-$/B^0_$K^+\pi^-$ ratio of decay rates

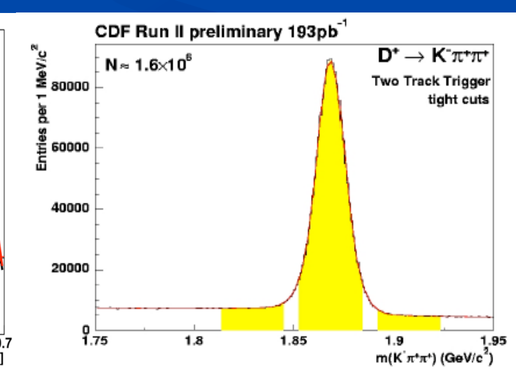
$$\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} = \left.\frac{N(B^0 \to \pi^+\pi^-)}{N(B^0 \to K^+\pi^-)}\right|_{\rm raw} \cdot \frac{\epsilon_{kin}(B^0 \to K^+\pi^-)}{\epsilon_{kin}(B^0 \to \pi^+\pi^-)} \cdot \frac{c_{XFT}(B^0 \to K^+\pi^-)}{c_{XFT}(B^0 \to \pi^+\pi^-)}$$

Different efficiency of the selection due to kinematical difference between the decays, and different decay-in-flight and interaction probability between *K* and *π*. Get from Monte Carlo the ratio of kinematics efficiencies.
~ 3% correction



π ionizes more than *K* ; this introduces a bias in the trigger on tracks within the drift chamber (XFT). Use data from unbiased legs in D^+_ $K^- \pi^+ \pi^+$ sample.
~ 5% correction





How dE/dx separates signals

To separate signals need all information. The dE/dx works best where kinematics fails (i.e. $B^0 \to \pi^+\pi^-$ vs $B^0_s \to K^+K^-$).

$$\mathrm{ID}(\mathrm{track}) = \frac{\left.\frac{dE}{dx}\right|_{\mathrm{meas}}(\mathrm{track}) - \left.\frac{dE}{dx}\right|_{\mathrm{exp}-\pi}(\mathrm{track})}{\left.\frac{dE}{dx}\right|_{\mathrm{exp}-K}(\mathrm{track}) - \left.\frac{dE}{dx}\right|_{\mathrm{exp}-\pi}(\mathrm{track})}.$$

<ID>(pion hypothesis) = 0
<ID>(kaon hypothesis) = 1

- $B^0 \to K^+\pi^-$
- $\overline{B}^0 \to K^-\pi^+$
- $B^0_s/\overline{B}^0_s \to K^+K^-$
- $B^0/\overline{B}^0 \to \pi^+\pi^-$
- $B^0_s \to K^-\pi^+ + \overline{B}^0_s \to K^+\pi^-$

PID separation $\pi\pi$/KK $\cong 2\sigma$